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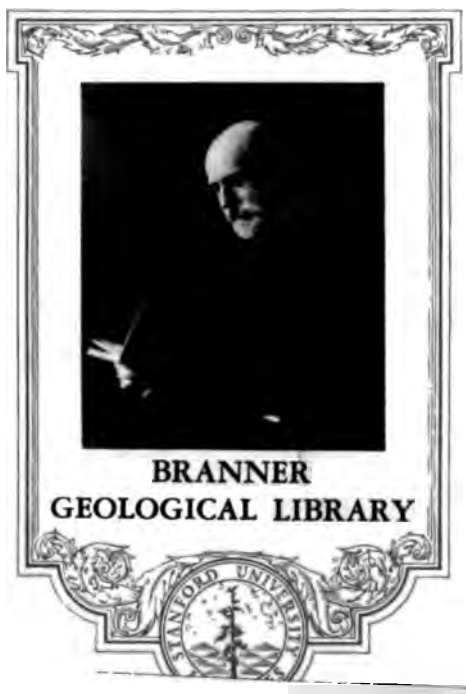
NORIA, OR WATER WHEEL, LIFTING FILLED BUCKETS.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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 1

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

PUMPING WATER FOR IRRIGATION

BY

HERBERT M. WILSON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1896

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, July 9, 1896.

SIR: I have the honor to transmit herewith a paper entitled "Pumping water for irrigation," by Herbert M. Wilson, geographer, and to recommend that it be published as the first number of the series of papers "in relation to the gauging of streams and to the methods of utilizing the water resources," whose printing was authorized in the act making appropriations for sundry civil expenses of the Government for the fiscal year ending June 30, 1897, approved June 11, 1896.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

PREFACE.

This paper by Mr. Wilson is the first of a proposed series of publications relating to water supply and irrigation. The object in view in undertaking a new series is to afford an opportunity for prompt publication of short reports, generally popular in character, relating to the water resources and the methods of utilizing these, with especial reference to the employment of water in agriculture. To reply to questions arising in various parts of the country regarding the progress of the investigation of the water resources and the facts relating to the available supply of water for irrigation, power, or domestic use, it is necessary to have pamphlets which can be sent out freely, and which, in order to answer the particular needs of individuals or communities, will not be too general in character. The series of bulletins issued by the Survey would serve as such means of communication were it not for the fact that by law these must be sold, and thus can not be used for official purposes or for placing the information acquired by investigation at once in the hands of the persons seeking to know the facts. By the law authorizing this new series it is possible for the Survey to distribute these papers to correspondents and to the numerous volunteer assistants who at one time or another have kindly aided by replying to letters of inquiry or schedules asking for specific data. Without such opportunities for distribution of small publications the officers of the Survey are placed in an embarrassing position, from the fact that they are compelled to ask favors in the way of statements and data of various kinds and are yet unable in general to more than thank the persons who have freely given their time to the preparation of letters and the filling out of blanks. Even when these persons have asked for a copy of the publication embodying the information which they have furnished, it has not been possible for a bulletin to be sent unless paid for by some member of the Survey.

Arrangements have been made for following this paper with others at short intervals treating of various subjects relating to the hydrography of the country and to details such as storing, pumping, and other processes of utilizing the waters. The following topics will probably be covered during the year: Measurements of Western streams; measurements of Eastern rivers; Northeastern water power; Southeastern water power; water supply of portions of Indiana and Ohio; artesian conditions of eastern Nebraska; underground water supply of

a portion of western Kansas; recent progress in artesian developments and irrigation in the Dakotas; artesian conditions of eastern Washington and portions of Idaho and Oregon; irrigation in the Salt River Valley of Arizona; methods of irrigation in California; seepage waters from irrigation; water storage in a portion of Wyoming; well waters of Nebraska; efficiency of windmills for irrigation; sewage irrigation, etc.

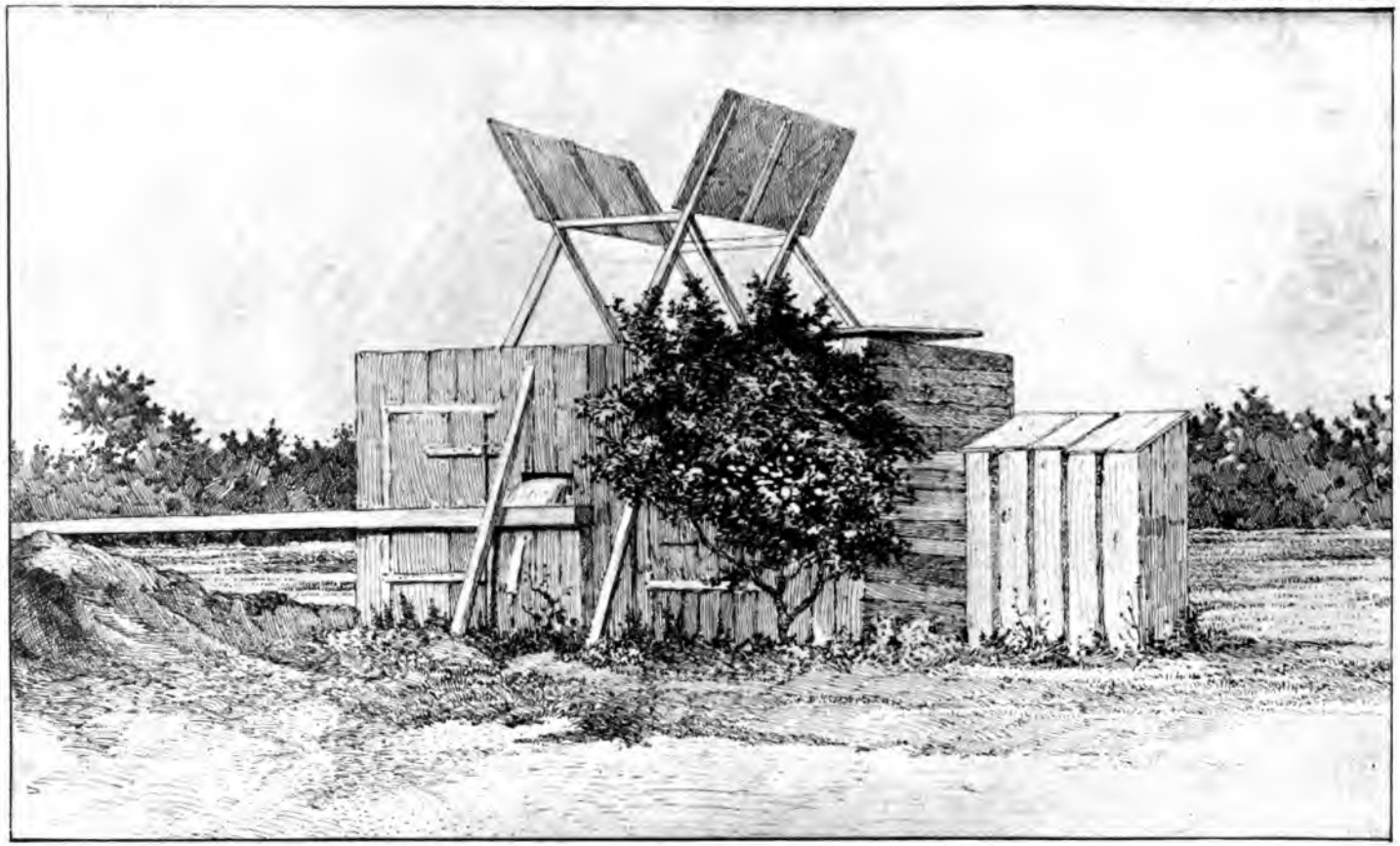
The data upon which these and other papers are based are being obtained largely through the field work of the Division of Hydrography, supplemented by correspondence carried on by means of schedules. Whenever practicable, arrangements are made with experts in various parts of the country to bring together the facts in their possession, rounding these out with additional investigation and preparing reports embodying this matter. Every effort is made, however, to preserve the distinctive character of an investigation and to push forward the work in directions where it is impossible for the individual to proceed unaided. It is not intended to bring together simply a lot of obvious facts and inferences relating to the water resources of the country, but to extend the bounds of knowledge in directions where exact information will have the greatest future value. It should be recognized that progress in new fields can never be so rapid as traveling over the old paths. It is only by bringing together clearly and concisely what is already known and building upon this that progress can be made in the utilization of the water resources of the country.

In the following paper by Mr. Wilson a general description is given of pumps and motive powers, and of windmills, water wheels, and various kinds of engines, noting the more important of these. The conditions surrounding the raising of water vary so widely that it is obviously impracticable to designate any one method as better than others, and a machine or device which to a man from one part of the country seems utterly useless may meet the requirements of some other locality. Mr. Wilson has therefore described, and in a few cases figured, devices which, while possessing no general applicability, yet contain suggestive features. It is not to be expected, for example, that in any part of the country human labor will be employed to any considerable extent in raising water, as is the case in Egypt, India, and other parts of the world; but the simplicity of the methods commend themselves, and a mention of these may serve to stimulate some inventive genius to make a practical application suitable for local needs. It is surprising to note how often the devices for raising water which in themselves are older than any written language have been reinvented and applied by the irrigators of the West. Again and again has the attention of the hydrographers of the Survey been called to the home-made devices for raising water based upon the principle of the Egyptian water wheel, or noria, or of the Persian bucket pump. These have

been devised by men who have considered the idea original with themselves, and could with difficulty be persuaded that their pet invention was old in the days of the Pharaohs.

In a new and rapidly developing country, such as the arid region, where methods of raising water for agriculture are constantly being modified and improved, it is desirable to have in mind all of the ways which have been found of value in the past. This pamphlet can by no means mention all or even a small part of these, being considered only as preliminary to more extended discussions. It is hoped that through the investigations of the Division of Hydrography a considerable body of accurate figures can be obtained concerning the methods and machinery for pumping large quantities of water now being put into operation. It may be interesting to note in this connection that as machinery is being modified to suit the requirements of lifting a large amount of water through a relatively small vertical distance, and at the least practicable expense, there is a tendency to return to the simple forms used by the primitive agriculturist, adapting these to modern machinery. For example, after trying all the complications of valves and pistons, of tight joints and complicated motions, designers of machinery are in some instances turning back to the old simple Persian wheel, which lifts water in buckets with the minimum of friction and of load to be raised.

F. H. N.



HOME-MADE WIND ENGINE, AS USED ON THE GREAT PLAINS

PUMPING WATER FOR IRRIGATION.

By Herbert M. Wilson.

INTRODUCTORY.

Until within the last decade the water supplies used in irrigation in our Western States were brought to the places of utilization almost wholly by gravity. There are, however, large volumes of water situated at such low levels that gravity will not carry it to the fields, and only in recent years have we come to a realization of the fact that this water may be raised by pumps or other lifting devices to elevations from which it will flow by gravity to the irrigable lands.

Extensive areas may be brought under cultivation through pumping after the supplies which gravity alone will bring have been entirely utilized. Not only is the water which may be raised from wells or low-lying streams available, but that which finds its way by seepage from irrigation canals and irrigated lands may be gathered into wells and pumped to the surface and again employed in irrigation. For, as irrigation is practiced, the subsoil becomes saturated, the ground-water level is raised, and much of the water delivered to the surface by gravity systems finds its way by seepage from the fields into the soil and may through pumping be used again in irrigation, thus adding to the duties of the ultimate sources of water supply.

The value of pumping for such purposes has been recognized for ages in the older European and Asiatic countries, and a large portion of the irrigation in Europe, India, Egypt, China, and Japan is carried on by such means. In Oriental countries pumping is performed almost wholly by animal or man power. In some portions of Europe, notably in Italy, some pumping is done by modern machinery, chiefly in raising water from existing low-level to high-level canals. In our own country numerous pumping plants actuated by wind, gasoline, water, and steam powers have been erected within the last few years, and they have proved so efficient and economic as to at once gain favor with Western irrigators.

The real value of pumping as a means of irrigation, and the extent to which it may be employed, are as yet scarcely appreciated. A great many windmills and some water wheels are utilized in our Western

States for this purpose, and a little pumping is done by steam and gasoline. But the value of the water supplies to be derived from lifting is sure to increase greatly as the cheapness and adaptability of this method come to be fully recognized. It is now a well-established fact that pumping occasionally furnishes irrigation water more cheaply than does gravity, both as regards first cost of the pumping plant, equivalent to the cost of water rights, and as regards the cost of maintenance and operation, which corresponds to the annual water rental or rate in the gravity system. In pumping, the source of water supply is more directly under the control of the irrigator, while he is troubled by none of the vexatious controversies arising from questions of priority of right or of water appropriation, of time of supply, and of rotation in the ditches; nor is he so likely to have his supply cut down in seasons of drought.

According to the figures given by F. H. Newell in the report on Agriculture by Irrigation, prepared for the United States census of 1890, the average first cost of water derived from gravity supplies for the whole United States was $8.15 per acre, varying between $3.62, the average for Wyoming, and $12.95, the average for California. The average annual water rental was $1.07 per acre, ranging between 44 cents in Wyoming and $1.60 in California. The average cost per second-foot of water on account of construction of some of the great gravity canals of the West, and based on the assumption that their whole supply was utilized, varied between $125 for the Bear River Canal, Utah, and $730 for the Turlock Canal, California. The cost per acre irrigated for the same works varied between $5 for the Bear River Canal and $14.50 for the Turlock Canal. The average cost per acre irrigated by some of the greater of the storage reservoirs of the West varied between $19.96 for the Hemet Valley Reservoir in California and $81.80 for the Sweetwater Reservoir in California.

On the other hand, numerous windmill pumping plants have been erected in the West, the first cost of which is equivalent to a charge of about $20 per acre irrigated, or less, while the cost of maintenance, equivalent to annual water rental, is practically nil. Hydraulic rams have been utilized in pumping for irrigation at a cost of about $10 per acre irrigated, with practically no charge for maintenance and operation. Gasoline pumping engines are extensively used in the West, the first cost of which has been equivalent to about $30 per acre irrigated, with a cost of operation of $1.25 per acre. Water-power pumping plants have been erected in the West at costs ranging from $1 to $15 per acre irrigated, and with operating charges varying between $1 and $2.50 per acre. Of steam pumping plants so far erected in the West the cost has ranged from $5 to $10 per acre irrigated, with an operating charge of from $1.50 to $3 and upward per annum per acre irrigated.

As an indication of the extent to which pumping, even in the crudest

forms, may be utilized, either to supplement gravity supplies or independently of them, it may be stated that in one small area in India, between the Ganges and Jumna canals, there are over 350,000 wells supplying water by lifting to 1,500,000 acres of crops. In Madras, India, 2,000,000 acres are irrigated by water pumped from 400,000 wells. In one small province in southern India there are over 100,000 wells, many of which have been sunk through hard rock to depths of from 80 to 90 feet and are capable of irrigating in ordinary seasons from 1 to 4 acres each. In our own country, on the great plains sloping eastward from the Rockies and on many of the broader intermontane valleys and in the great California valley, wherever the wind is comparatively constant and of relatively high velocity, vast areas of land may be brought under cultivation through irrigation by water lifted from wells by means of windmills. In like manner, streams which are flowing between steep banks may not only furnish water supplies for irrigation by means of pumping, through wind, steam, or gasoline power, but, if of sufficient size, may furnish water power for lifting. The extent to which water supplies are to be derived from such sources is yet difficult to estimate, but it is certainly within the realm of probability that eventually nearly one-half as much area may be brought under cultivation through lift as through gravity supplies.

PUMPS AND MOTIVE POWERS.

Pumps are machines for elevating water, and they may be divided into two principal parts: the pumping or water-elevating device, and the power by which this is operated. Pumps, as such, may be divided into four general classes, according to the principle on which they raise water, namely: (1) lift pumps, (2) force or plunger pumps, (3) rotary and centrifugal pumps; (4) mechanical or siphon elevators. The principle of lift and force pumping may be combined in one mechanism, and this may be either reciprocating or rotary, or it may be single or double acting.

The motive power may be derived from one of the six following sources, namely: animal, wind, water, hot air, explosive force of gas, and steam. Force, lift, and centrifugal pumps and mechanical elevators may be operated by almost any one of the various motive powers. Distinguished from these are three additional classes of pumping mechanisms, in which the motive power and the pump are inseparable. These are (1) injectors, vacuum pumps, and pulsometers, in which steam is the motive power; (2) hydraulic rams and hydraulic engines, in which water is the motive power; and (3) siphons and siphon elevators, in which atmospheric pressure is the motive power.

Lift pumps operate by drawing water through a suction pipe as the pump bucket ascends; as the bucket descends the water is forced through a valve in it, and is then lifted as it reascends. This variety of

pump is dependent for its operation on atmospheric pressure for the creation of a partial vacuum below the pump bucket.

Force pumps draw water through a suction pipe as do lift pumps, but to less heights, and the water is raised above the bucket by the action of a piston or plunger which forces it through a delivery valve. Force pumps may be single or double acting, and nearly all steam pumps are of the latter variety, the discharge of these being practically continuous, for as the water is drawn in at one end it is forced out at the other.

Centrifugal pumps depend for their action on a disk to which are attached propeller blades revolving inside a chamber. These propeller blades create a partial vacuum which lifts water, though but a few feet, into the chamber by suction, whence it is forced by the following propeller blade. Rotary pumps are practically revolving piston pumps, differing from the latter chiefly in that the propelling piece moves forward continuously.

Mechanical water elevators include not only the various patented devices by which water is raised by means of disks or buckets arranged on a revolving chain, but also the various ancient mechanisms employed in oriental lands for lifting water from wells. Among these are chain pumps, Archimedean screws, the tympanum, Persian wheel, noria, the latha or basket, the doon, the lat or paecottah of India, which is the shadoof of Egypt, the mot, and numerous other curious devices.

All the motive powers except wind may be used to operate any of the various classes of pumps. Ordinarily, however, animal power is used to operate the lighter forms of pumping machinery which are intended to elevate small quantities of water, and the common lift and force pumps and mechanical elevators of various kinds. Wind is employed almost exclusively for the operation of lift and force pumps, as it is too uncertain in its action to work well with ordinary centrifugal pumps or many forms of mechanical elevators.

The various motive powers may be divided into two general classes, according to the manner in which they are attached to the pumps. These are (1) direct-acting pumps; (2) fly-wheel and belting pumps.

Direct-acting pumps have, as a rule, no rotary motion, their action being reciprocating, both steam and water cylinders being mounted on a solid bed plate, so that the piston rod, which produces the power, has attached to it the plunger which elevates the water. Fly-wheel pumps may be direct-acting pumps or they may have the motive power at some distance from and independent of the elevating pump and be connected therewith through shafting or belting or some other mechanical device. The latter forms are usually not so satisfactory or reliable in their operation where used for irrigation, as they generally require more skilled attendance than do direct-acting pumps, though, on the other hand, their efficiency is often higher.

In the choice of pumping machines the irrigator should consider, among other things, the motive power which is most available and cheapest for his purposes, and the quantity and accessiblity of his water

supply. Having gotten from these considerations an idea of the general form of pumping machine which will best suit his purposes, he will do well either to consult a mechanical or an irrigation engineer or, if the extent of his enterprise will not warrant this, to obtain advice from various makers of the form of pumping machine which he anticipates using. These persons will furnish him with details of cost and assist him to select the variety of machine best suited to his purpose, and he will thus be able to choose the most economic and efficient apparatus.

The pump and motive power which are to be employed in each particular case depend on the service to be performed and on various local modifying conditions. The variety of pump must be chosen according as greater or less volumes are to be elevated to greater or less heights. The motive power must be selected according to the pump chosen, the work to be done, and the fuel available, be this animal, air, water, gasoline, wood, or coal. Where means are limited and the area to be irrigated is small, the motive power chosen will usually be either animal or water. The first is cheapest of installation, but least economical, and the latter is next cheapest, providing a sufficient water supply is available for the operation of an ordinary mid-current undershot wheel, a noria, or a hydraulic ram. Where the area is small but the means at the disposal of the irrigator are less limited, animal power will usually be left out of consideration, and the choice will rest between wind, water, hot air, gasoline, and steam pumping engines. If the wind be reasonably steady and the facilities for the construction of a storage tank be good, wind motors, though not less expensive to install than some others, and not the most reliable, are least expensive and troublesome to maintain and operate. Where water is abundant, it furnishes, through water wheels, turbines, or water engines, the next least expensive power to maintain and operate, though not the cheapest to install. The class of water motor selected will depend wholly upon the fall and volume of motive power available and the height to which the water is to be raised. Hot-air and gasoline engines furnish the most reliable power for pumping water, and are less difficult to operate than steam engines. Gasoline engines are especially economical where coal or wood are expensive, though hot-air engines have a wide adaptability in the variety of fuel which they may utilize. Steam engines, where coal is cheap, furnish the most satisfactory motive power, but are generally not so economical to operate, especially where small areas are to be irrigated. For the pumping of large volumes, water and steam are the only competing motive powers.

The irrigator who proposes installing a pumping plant should consider all the various circumstances which affect the case under consideration. He should carefully weigh the necessity of having a permanent and steady supply, the inaccessibility of the plant for repairs or replacement of broken parts, the relative cost and accessibility of different kinds of fuel or of water, and the degree of intelligence and skill possessed by those who are to operate the machine employed.

ANIMAL MOTIVE POWERS.

Among the oldest and best known of these is the common domestic well sweep, which is the paecottah of India (fig. 1) and the shadoof of Egypt. In India this is operated by from one to two men who labor from six to eight hours daily and by its use raise from 1,000 to 3,000

FIG. 1.—Raising water from well in India by paecottah.

cubic feet per day. This apparatus is usually employed for but small lifts of from 5 to 12 feet, though under the name of shadoof in Egypt it is commonly employed for much greater lifts by using a series of several sweeps arranged one above the other, as illustrated in fig. 2. By

the latter means three men will irrigate from 2 to 4 acres a season. The average cost of irrigation by this means has been estimated in central India to be about $5 per acre irrigated. The paecottah consists essentially of a leathern or earthen bucket hung from the light end of a pole which is pivoted near its farther extremity and oscillates in a vertical plane, the short end of the pole being counterbalanced by a weight, so that the bucket when full requires but little force to raise it. The man working this contrivance stands on the edge of the well and uses his weight to depress the bucket into the water, whence it is raised largely by the force of the counterweight and the water is delivered into a small ditch which leads it to the irrigable fields.

Others of the mechanical devices employed in India for utilizing man power to lift water are the latha, or basket (fig. 3), and the doon (fig. 4).

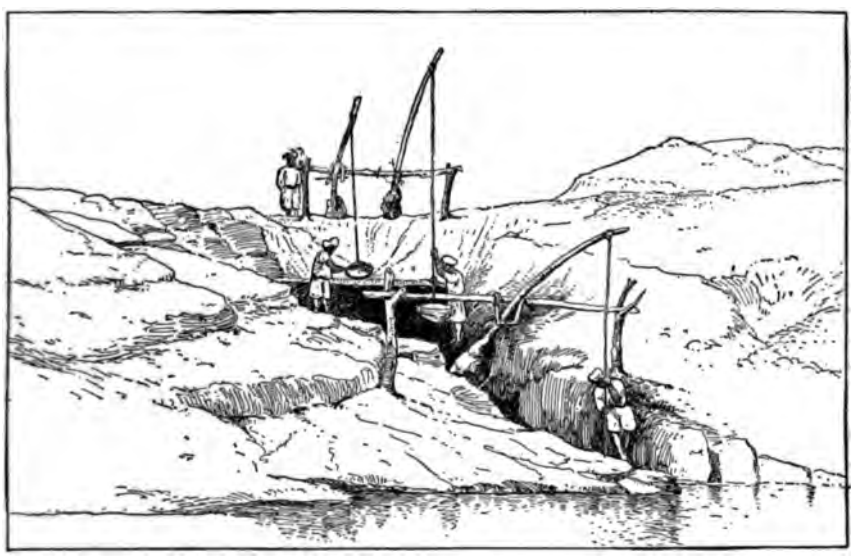


FIG. 2.—Series of shadoofs as used in Egypt.

The former is used for very small lifts of from 2 to 4 feet, and is operated by swinging the basket backward and forward in such manner that in swinging in one direction it dips into the water and is filled, and on its return to the farther end of its oscillation it is skillfully twisted so as to throw the water into a ditch. This apparatus is always operated by two men and is estimated to be capable of lifting 20,000 cubic feet of water 1 foot in height in ten hours, and the cost of its operation in India is estimated to average $3 per acre irrigated, though this figure is doubtless too low. The doon is likewise used for very small lifts, and consists of an oscillating trough [1] pivoted near its center, so that one end is alternately pressed into the water and raised above the level of delivery, the water flowing from the other end into the ditch. The

[1] Irrigation Works in India and Egypt, by Robert Burton Buckley, 1893, 348 pp.

weight of the water is partly balanced by a counterpoise, so that the man who stands over the water on the plank can depress the end of the doon into the stream by his foot, and then by stepping upon the

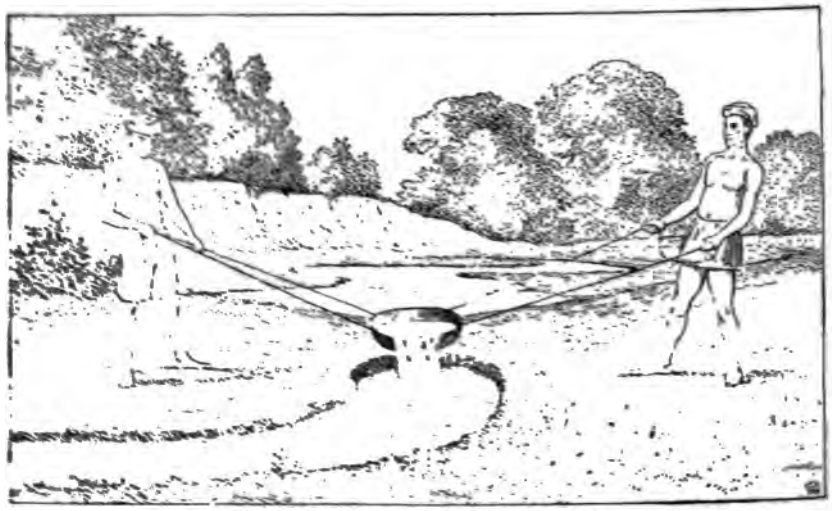


FIG. 3.—Swinging water by basket, or latha.

plank he can, with a slight exertion, slope the trough to the point of delivery. This apparatus is quite efficient for trifling lifts, and is estimated to irrigate 1 acre at an average cost of $1.00, Indian wages.

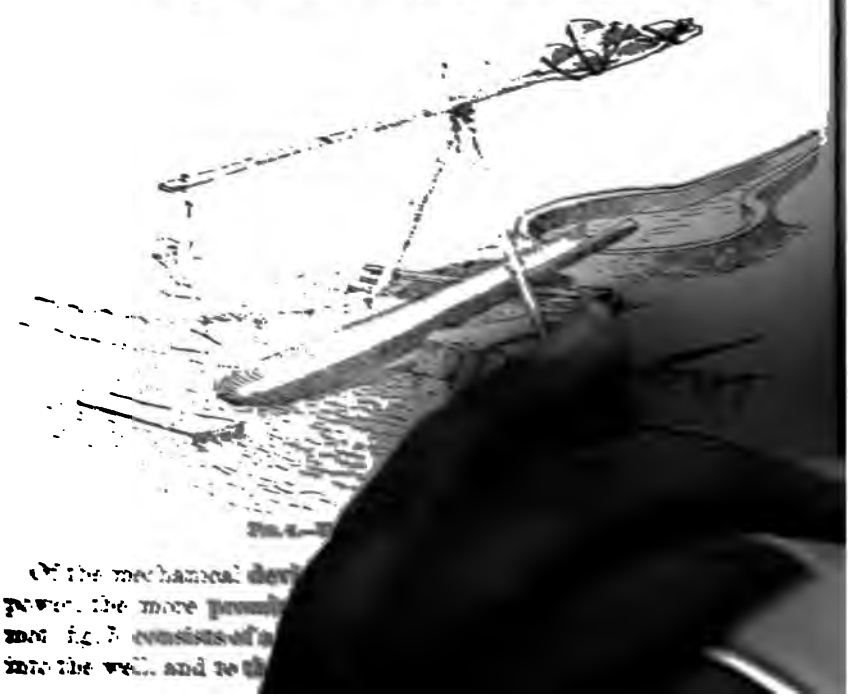


FIG. 4.—[illegible]

Of the mechanical devi[illegible] power, the more promi[illegible] mot fig. 5 consists of a [illegible] into the well, and to th[illegible]

tacle. This is raised by two bullocks walking away with the rope down an incline, and thus drawing the bucket to the top of the well, where it is emptied into a distributing ditch. These animals are frequently so well trained that after reaching the bottom of their walk they return backward and at quite a rapid rate up the slope, while at other times they are trained to turn around and walk forward up the slope, again turning as they reach the top. The mot is frequently employed in lifting water from depths as great as 40 to 50 feet. It is operated by one or two men, according to the mode of construction of the water bag. In some cases this has to be emptied by one man standing at the well curb while another drives the bullock; in other cases the bag is emptied automatically by an ingenious attachment of the rope to an opening at its lower end, and one man only is employed, to drive the animals. With the mot it is estimated that two bullocks work-

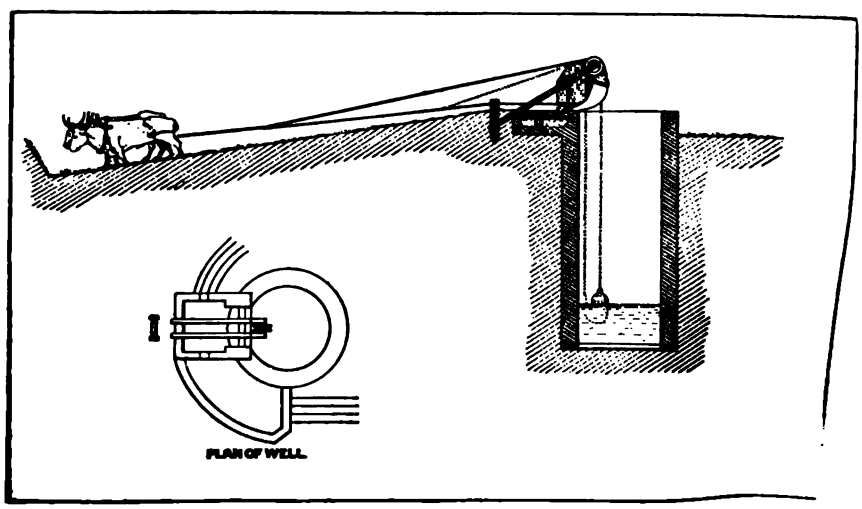


FIG. 5.—Bullocks lifting water by bag, or mot.

[illegible] hours a day will irrigate 3¾ acres in a season of ninety days, [illegible] irrigation by this [illegible]

Recently there have been patented in this country a number of adaptations of the Persian wheel, skillfully designed and constructed in such manner as to be more efficient than the ancient oriental device. One of these consists of large metal buckets hung on heavy linked chains which revolve over the vertical wheel and dip into the source of water supply beneath. This wheel is operated by iron-cogged gearing, turned by sweeps to which one or more draft animals are attached (fig. 7). These wheels have capacities varying from 500 cubic feet per hour for one horse to 2,000 cubic feet per hour for four horses for a depth of 20 feet, and their first cost ranges between $200 and $500. There are also on the market in this country a number of mechanical devices for utilizing animal power in pumping, consisting of various forms of sweeps to be operated by horses walking in a circle or by treadmills for utilizing horse, bullock, or sheep power through gearing and shafting. Most of

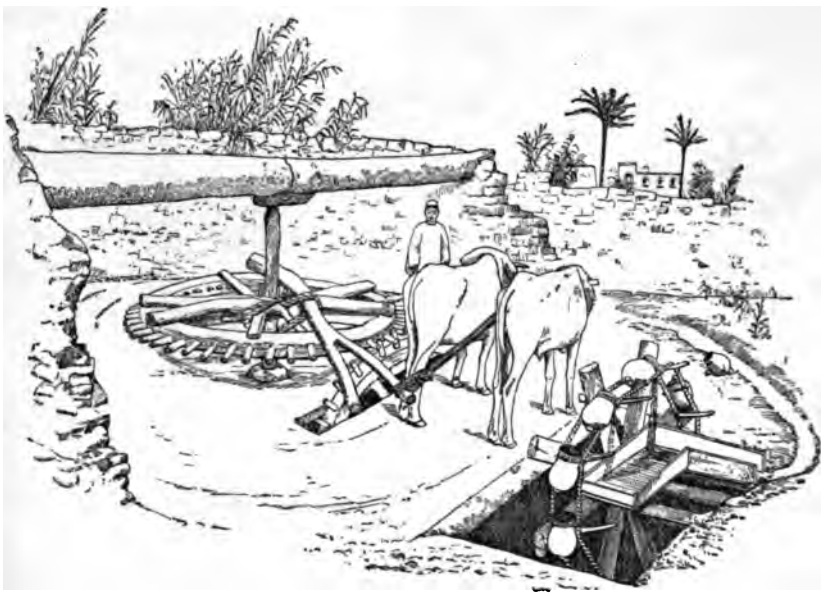


FIG. 6.—Persian wheel driven by bullocks.

these are simple in construction and operation and are not liable to get out of order. They furnish motive power usually for lifting water by means of mechanical elevators or force or centrifugal pumps, and are, with their pumps, capable of lifting sufficient water with a two-horse device to irrigate from 2 to 5 acres per season, while this amount could be at least doubled if a storage tank of sufficient capacity were provided for retaining water during periods when not wanted for immediate use.

An ingenious device for lifting water by man power is the double zigzag balance of Asia Minor and Egypt. This contrivance (fig. 8) consists of a double series of wooden troughs or gutters, the extremities of which are fastened and rise one above the other at an acute

angle. At the junction of each pair of troughs are placed wooden valves to prevent the return of water. This balance is suspended at its upper end on a level with the irrigating ditch, and is caused to oscillate about this as a center, much as does a pendulum, the motion being produced by a couple of men pulling on ropes. The lower ends of the troughs dip into the stream from which the water is to be lifted, and at every oscillation each series of troughs empties its water into that immediately above, until it is finally lifted to the summit of the balance, whence it is discharged into the irrigating ditch.

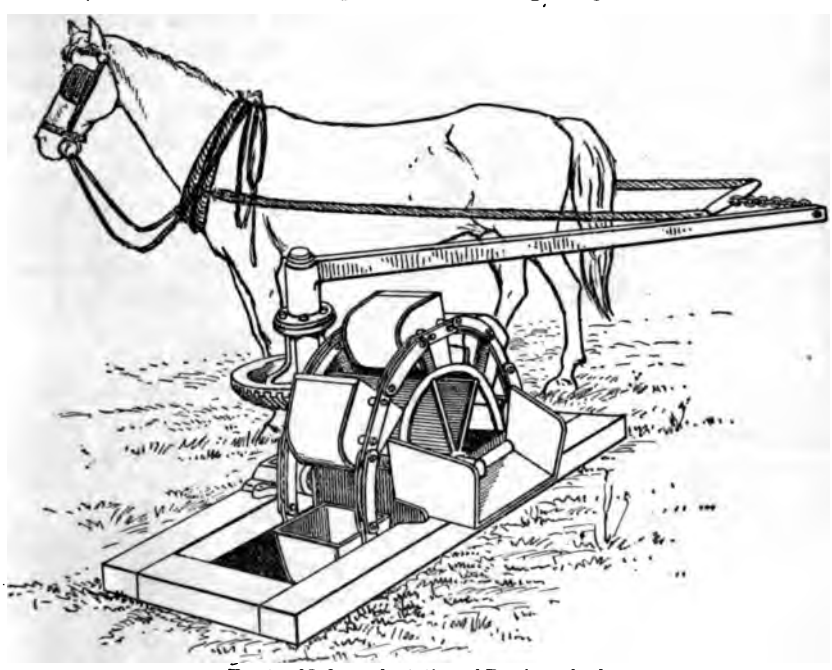


FIG. 7.—Modern adaptation of Persian wheel.

WINDMILLS.

Irrigating water is now being extensively pumped by windmills in various portions of the West, notably in the San Joaquin Valley of California, in Kansas, Nebraska, and the Dakotas, and elsewhere on the Great Plains east of the Rocky Mountains. Until recently windmills have been most extensively employed for pumping water for domestic use, but as water supplies for irrigation have become scarcer, and as practical farmers have come to appreciate the value of irrigation, they have in seeking new water supplies resorted quite extensively to windmills as motive powers for pumping water. The chief objection to windmills for this purpose is that they are dependent upon the force and regularity of wind for their operation, and as a result they do not furnish as steady and reliable a power as do water, steam, and other agents. This objection is, however, not serious on the Great Plains between the Rocky Mountains and the Mississippi River, especially if

storage reservoirs are employed as an adjunct to the mills, for in that region there is, throughout most seasons, a sufficiently steady and powerful wind to keep the wind wheels constantly turning. In other portions of the West the winds are less certain in their action, and may fail the farmer at the very time when he is most in need of a water supply.

Windmills are too frequently employed to pump water for irrigation

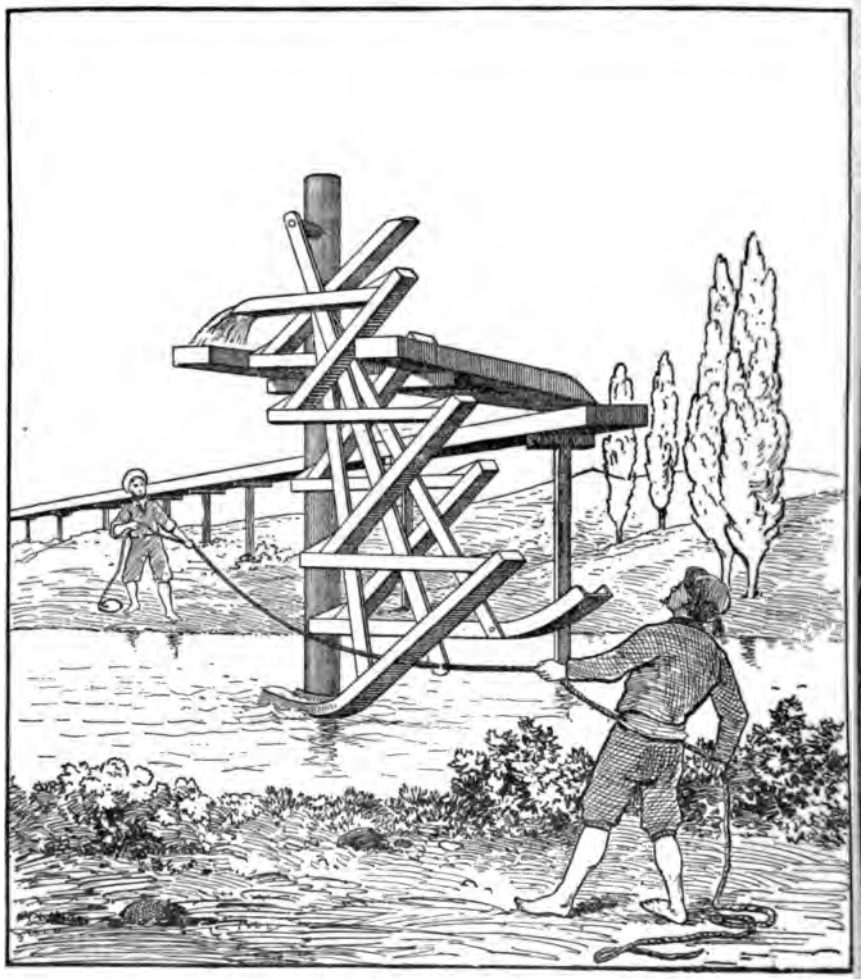


FIG. 8.—Double zigzag balance.

either from the uncertain supplies derived from drive wells or without the aid of a storage tank or reservoir in which to retain the surplus pumped at such times as it is not utilized in irrigation. As a result the supplies which they furnish are insufficient and unsteady, and this has led to their condemnation. The fault in such cases has not been with

) mill but with the user. In order to obtain good results from wind-lls they should not be used where the wind is uncertain and shifting, in connection with a poor pump, or where a water supply equal to ;ir full pumping capacity is not available; and they should invari-ly be supplemented by an ample storage reservoir.

The wind may blow at any time during the twenty-four hours, and no more likely to blow in the daytime than at night, when water is t used in irrigating the fields. It is also likely to be as active at sea-ıs when irrigation is not in progress and during the late winter and ring months as when water is being run upon the fields. For secur-', therefore, and in order to irrigate a reasonable area from a pump of ven capacity, ample storage room should be provided for the water ıich can be pumped during several weeks. This storage room may obtained by using one of the various forms of elevated wooden ıks supplied by windmill makers; or, better, if the windmill can be ;ated at a high point on the farm an artificial reservoir may be con-ıucted of earth at this point and be suitably lined with earth puddle asphaltum. It should, if possible, be sheltered from the sun by a)f, so as to decrease losses by evaporation. Such a storage reservoir n easily be given sufficient capacity to retain a much larger volume water than can economically be stored in a wooden tank.

The amount of work which a windmill will perform depends on the ce and steadiness of the wind, the size of the wind wheel, its design d construction, and its location. An average wind velocity of not s than 6 miles per hour is required to drive a windmill, and, on average, winds exceeding this velocity are to be had during eight urs per day; hence, about two-thirds of the total wind movement is ailable for work. According to reports of the United States Weather ıreau, the average wind movement of the entire country is about 6,000 les per month, or over 8 miles per hour. These averages are some-ıat exceeded in Dakota, where the hourly velocity is from 10 to 12 les, as it is in Nebraska, Kansas, and neighboring States, while they) too great for some other portions of the arid West. The following)le gives roughly the force of the wind for ordinary velocities:

TABLE I.—*Wind velocity and power.*

Miles per hour.	Velocity in feet per second.	Pressure per square foot, in pounds.	Miles per hour.	Velocity in feet per second.	Pressure per square foot, in pounds.
6	8.8	.1	30	44.0	4.4
10	14.7	.5	35	51.3	6.0
15	22.0	1.1	40	58.7	7.9
20	29.3	2.0	45	66.0	10.0
25	36.7	3.1	50	73.3	12.3

Table II, which is derived from Mr. A. R. Wolff's treatise on the windmill,[1] and is based on scattered data of actual performances, shows the capacity of a windmill having various diameters of wheels with an assumed average velocity of wind of 16 miles per hour and working eight hours per day.

TABLE II.—*Capacity of windmill.*

Size of wheel, in feet.	Revolutions of wheel.	Gallons of water raised per minute to an elevation of—						Horse-power developed.
		25 feet.	50 feet.	75 feet.	100 feet.	150 feet.	200 feet.	
10	60 to 65	19.2	9.6	6.6	4.7	.....	.....	0.12
12	55 to 60	33.9	17.9	11.8	8.5	5.7	.....	.21
14	50 to 55	45.1	22.6	15.3	11.2	7.8	5.0	.28
16	45 to 50	64.6	31.6	19.5	16.1	9.8	8.0	.41
18	40 to 45	97.7	52.2	32.5	24.4	17.5	12.2	.61
20	35 to 40	124.9	63.7	40.8	31.2	19.3	15.9	.78
25	30 to 35	212.4	107.0	71.6	49.7	37.3	26.7	1.34

According to Mr. Wolff's estimate, the cost of operating a windmill for a 25-foot lift, including interest on first cost and charges for maintenance, ranges from ¾ cent per hour for a 10-foot wheel to 2½ cents for a 16-foot wheel and 4¼ cents for a 25-foot wheel. From an inspection of the foregoing, it is evident that the windmill is one of the most economical of motive powers. Its operation calls for no expense for fuel and little for attendance or repairs. In comparison with it the steam engine requires large expenditures for fuel, repairs, and attendance, and nearly all water motors call for heavy outlay in providing and maintaining their water supply as well as for repairs and attendance. It appears that on the average the economy of a windmill is at least one and one-half times that of a steam pump, while it has an additional economy over the latter because of the attendance and repairs demanded by the steam boiler.

Extensive experiments with a view to obtaining a comparison of the efficiency of various windmills have been recently made by Mr. J. A. Griffiths in Australia. The highest net efficiency observed in Mr. Griffiths's experiments with the wind blowing 7 miles per hour was 25 per cent. Table III gives the results of his experiments for the five American-made wind wheels tested.[2]

[1] The Windmill as a Prime Mover, by Alfred R. Wolff, M. E., John Wiley & Sons, New York, 1890, 161 pp.

[2] Windmills for raising water, John Alfred Griffiths: Minutes of Proceedings of the Institution of Civil Engineers, Vol. CXIX, London, 1895, pp. 321–343.

TABLE III.—*Capacities and efficiencies of several windmills.*

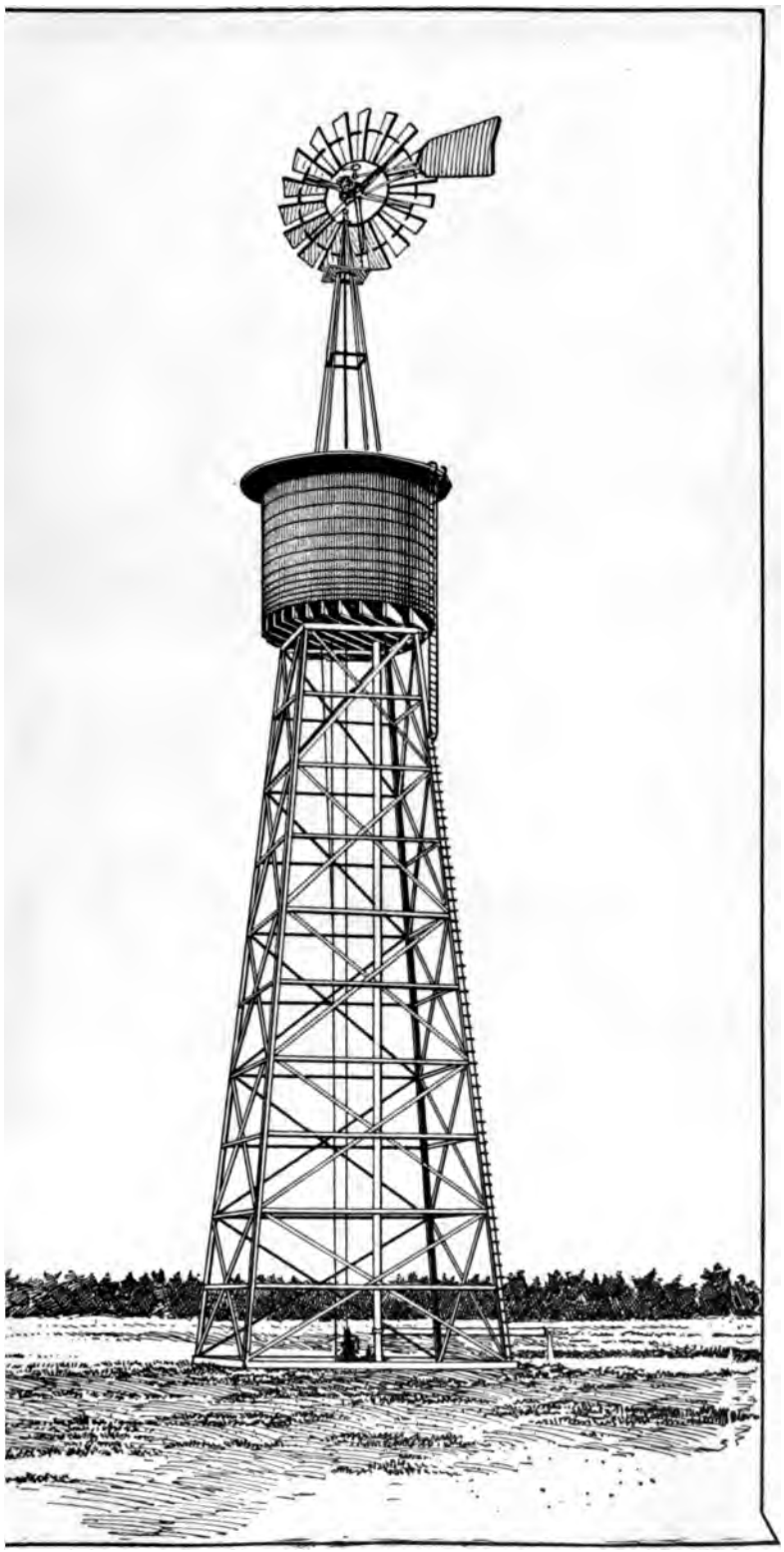
	Stover solid hand-control rudder.		Perkins solid automatic rudder.	Althouse folding rudderless.		Carlyle automatic rudder.
Outer diameter of sail wheel.....feet..	11.5	11.5	16.0	14.2	10.2	9.8
Inner diameter of sail wheel.....do...	4.5	4.5	6.0	4.5	3.8	4.2
Gross area of sail wheel.....square feet..	104	104	201	157	81	80
Weather angle at outer ends of vanes.....degrees..	43	43	36	30	28	50
Diameter and stroke of pump.....inches..	3 by 4	3 by 4	3 by 10½	3 by 10	3 by 4½	3 by 4
Average head of water during tests.....feet..	29.2	61.2	39.0	66.3	38.7	30.7
At maximum efficiency:						
Velocity of wind per hour.....miles..	5.8	6.5	6.0	7.0	8.5	6.0
Velocity of mill per minute.....revolutions..	13	13.3	7.5	12.6	20.5	12.5
Actual horsepower.....	.011	.025	.024	.065	.028	.012
Horsepower per 100 square feet of gross area.....	.011	.024	.012	.041	.035	.015
Maximum net efficiency.....per cent..	8.7	14.4	8.9	19.3	9.0	10.4
In 100 average hours, calm locality:						
Average quantity of water lifted per hour.....gallons..	153	135	259	267	115	145
Average continuous horsepower developed per 100 square feet.	.022	.040	.025	.057	.028	.028
Average continuous gross horsepower developed.....	.023	.042	.050	.089	.023	.022
Average net efficiency.....per cent..	2.1	3.9	2.5	5.5	2.7	2.7
In 100 average hours, windy locality:						
Average quantity of water lifted per hour.....gallons..	287	271	525	540	237	270
Average continuous horsepower developed per 100 square feet.	.041	.080	.051	.115	.057	.052
Average continuous gross horsepower developed.....	.043	.083	.102	.18	.046	.042
Average net efficiency.....per cent..	.28	1.11	.71	1.59	.78	.72

While designed on lines somewhat similar to those of a water wheel, a wind wheel differs from the latter in that it is wholly immersed in a sea of air, while the water wheel is acted upon by a limited current of water; therefore, while the common paddle wheels of an undershot water wheel develop considerable power, as one side only is immersed in the stream, no result can be obtained by using such a form of wind wheel unless one side of the wheel be screened from the air. This effect is obtained in a crude wheel used in some portions of the West, and known variously as the Wind Rustler, Jumbo, or Mogul windmill (illustrated on Pl. I). Such a contrivance is of course less efficient and less reliable than the regular form of windmill, because it is placed so near the ground that it does not receive the full force of the wind. Moreover, the directing of the mill to the wind is not under the control of the irrigator, and it will accordingly operate only when the wind is blowing in a direction nearly at right angles to its horizontal axis. Such a contrivance may serve as a makeshift for the pioneer who does not possess means with which to purchase a well-designed wind wheel, enabling him to bring under cultivation a trifling area of land, and to get a start in life. A number of Moguls are successfully employed in the West which have wheels of 14 to 18 feet diameter, 6 to 8 fans of about 2 or 3 by 10 to 15 feet, and are each capable of pumping sufficient water to irrigate 1 to 2 acres with a 25-foot lift. Such a contrivance costs from $20 to $100, or even more, according to the amount of hired labor employed in its construction.

The well-known forms of windmills consist of arms, cross bars, and clothing, and their vanes are made plane, warped, or concave. The older type of cloth or canvas-sail mill is common in Europe, especially in Holland, and has generally four arms. The narrow part of the sail is usually covered with a wind board, and the broader with wind slats of wood or with sailcloth. Modern American mills differ from the older European type in that they are chiefly of the propeller form, and instead of a small number of sails of considerable width are made with a great number of blades or slats of small width. They also differ in appearance from the European mill, as the wheel presents a closed surface as compared with the large open spaces between the arms of the European sail wheel. As a result of this mode of construction, the American mill is lighter in weight as well as in appearance than the European mill, and though the wide angle of the vane is not so advantageous as in the sail mill, the surface presented for a given diameter is sufficiently greater to more than compensate.

The direction of the wind is changeable, and, in order that the shaft on which the wheel revolves may be properly directed toward it, its support must be movable, so that it can revolve about a vertical axis. This revolution is effected in various manners in the old European[1] mills, and, according to the method employed, they may be divided

[1] The Mechanics of Engineering and of Machinery, Weisbach and Du Bois, Vol. II, Hydraulics and Hydraulic Motors, John Wiley & Sons, 1889.



STEEL WINDMILL AND TOWER CARRYING TANK.

into three classes: the post mill of Germany, the tower mill of Holland, and a type midway between these two (fig. 9), being like a tower mill in which nearly the whole mill revolves, as in a post mill, not merely the upper portion alone, as in the tower mill proper. In the post mill the entire building, wheel and all, revolves about a central fixed column or post. In the tower mill the dome-shaped cap, which is

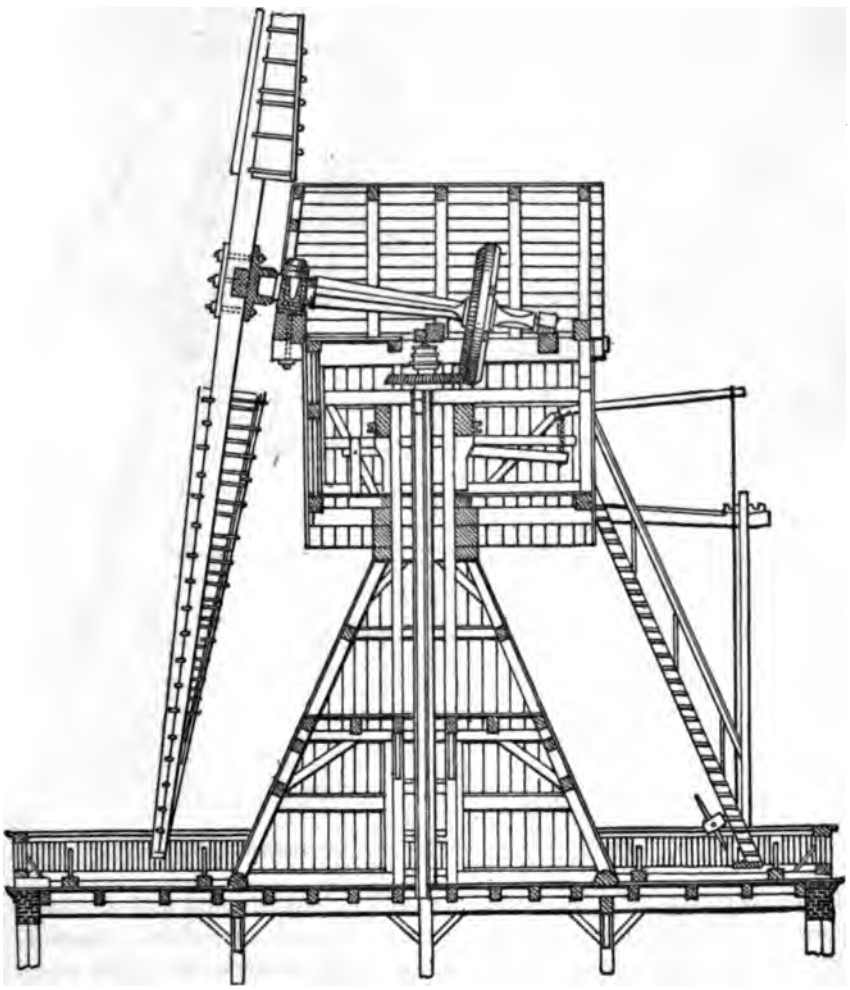


FIG. 9.—Old type of windmill, mounted on central column.

the only movable portion of the mill, rests on a stationary tower of wood or masonry. The wind shaft carrying the wheel is set at a slight inclination to the vertical. This shaft transfers its power by means of cogwheels to the vertical shaft which turns the mill and actuates the pump. The wheel is turned in the direction of the wind by means

of a lever or hand wheel or by means of a large vane or wind wheel (fig. 10) attached to a secondary axis.

The several types of American windmills are distinguished by the form of the wheel and the mode of regulating or governing its position and direction so as to obtain a uniform power and rate of revolution under varying wind velocities. These mills may be divided into two principal classes, namely: (1) sectional wheels with centrifugal governor and independent rudder, and (2) solid wheels with side-vane governor and independent rudder. In addition to these are a number

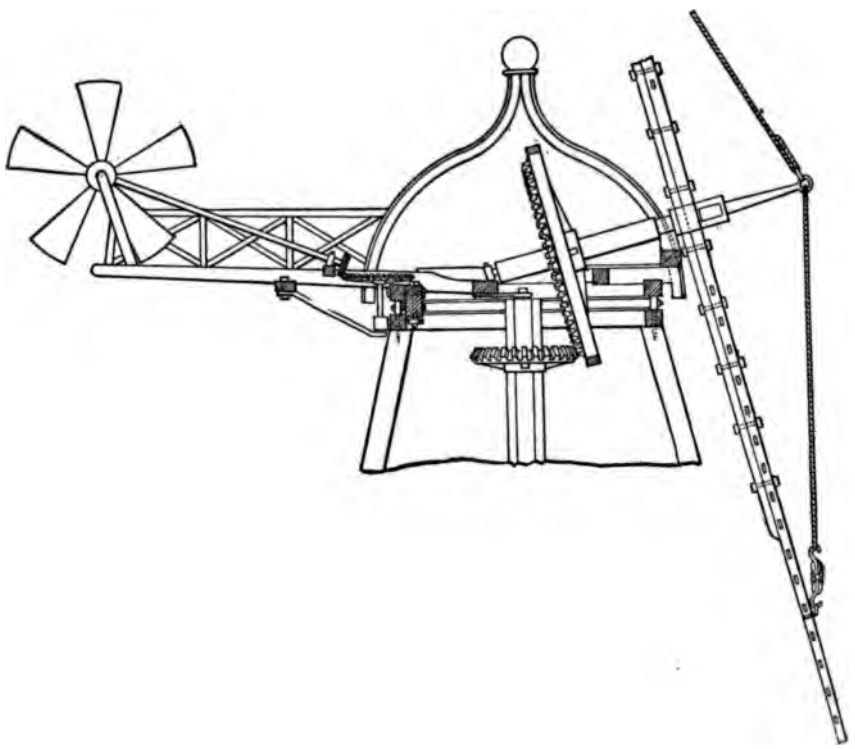
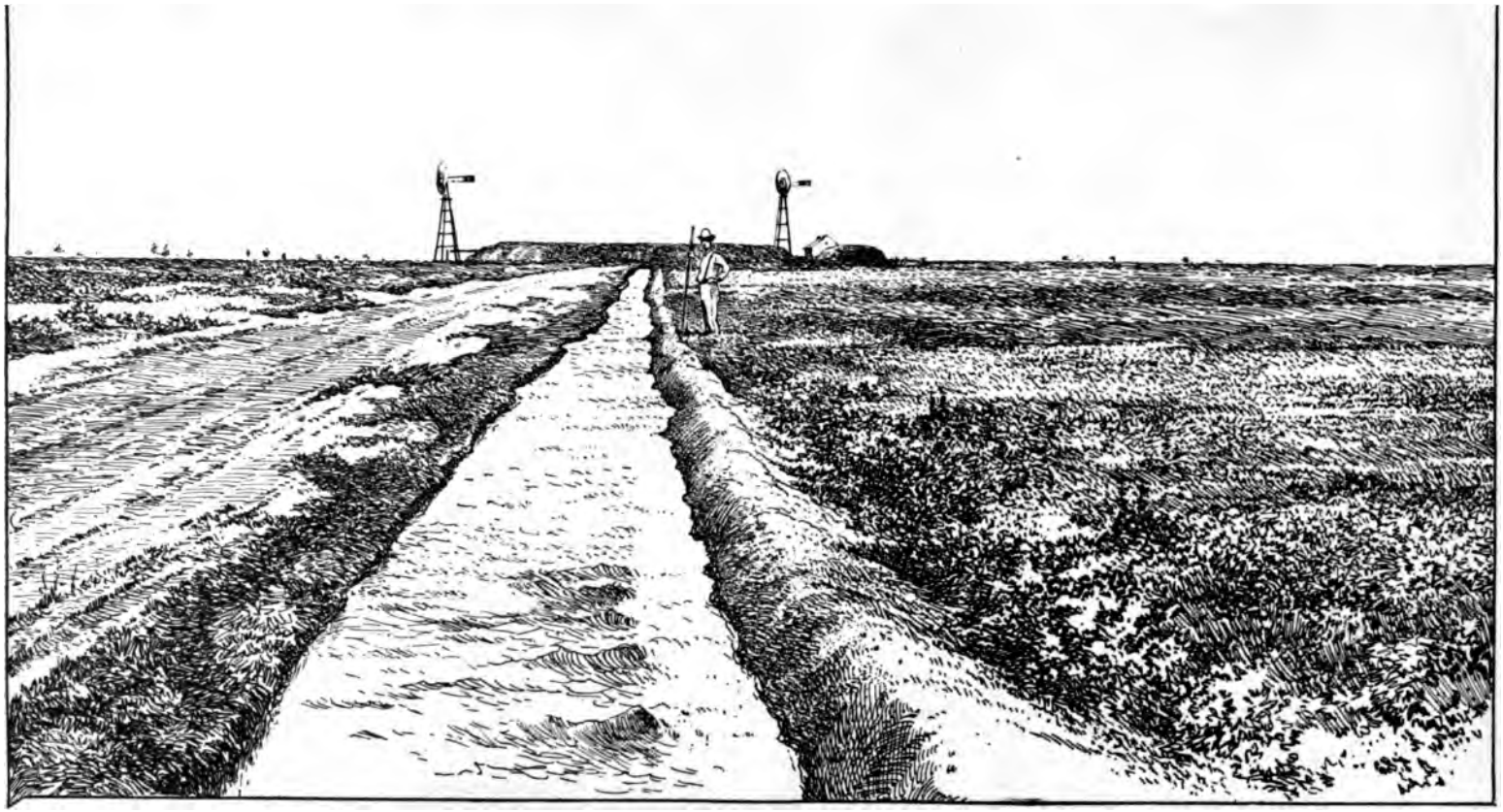


FIG. 10.—Early form of head of tower windmill.

of special types, including various combinations of solid and sectional wheels and those having varying arrangements of rudder. Some of these special types are rudderless, the wind pressure upon the wheel being relied on to bring it into direction.

In selecting a windmill to perform a given duty the irrigator will have many forms from which to choose, and, after a careful perusal of catalogues and circulars furnished by different makers, must use his own discretion in choosing that which seems to best fit his requirements. Below are enumerated a number of the more prominent American windmills. No attempt is made to name them in the order of excellence.



IRRIGATING DITCH AND EARTH RESERVOIR.

NORIA, OR WATER WHEEL, LIFTING F[illegible]

Moreover, no attempt is made to present a complete list, many forms of mills being on the market which may be equally as good as those named.

Of side-vane governor mills the Corcoran and Eclipse are excellent examples. Of centrifugal governor mill the Halliday and Althouse are good examples, the latter being folding and rudderless. The Buchanan is a good example of a special form of wheel dependent for its regulation on the tendency of the wheel to go in the direction it turns as the velocity and wind pressure increase. The Stover mill has a solid-sail wheel with vanes so regulated that it may be reefed, stopped, or otherwise controlled to go slowly in heavy winds. The Perkins mill has a solid wheel with metal vanes, and an automatic rudder, which also acts as an automatic regulator. This, like many of the more recent American mills with metal vanes, as the Aermotor, Gem, Crane, and Ideal, is back-geared. The Aermotor is one of the most popular of this class of modern American windmill with steel vanes. The Leffel windmill has metal vanes made on a helical curve, and depends for regulation on the fact that the center line of the wheel shaft stands off from and parallel to the plane of the rudder.

Others of the modern American type of metal-vane wheels are the Cyclone and Woodmanse. The Advance is of the automatic-regulating rudder type, and has both steering vane and governing rudder. The Carlyle is a special type, having a rudder arranged to reef the sail in storms, and so attached by an adjustable cam as to cause the center of gravity of the rudder to rise as the rudder falls toward the wheel.

Drive wells should not, as a rule, be relied on to supply windmills, as the flow of water from such wells is usually limited, because of the small stratum of subsurface water from which they derive their supply. The well should be of ample size and properly lined. It is not infrequently necessary to place the pump down in the well if the depth of this below the surface is such that water can not be successfully raised by suction. The windmill should be placed directly over the well or other source of supply, and on a wooden or iron tower or scaffolding sufficiently high to raise the wheel 20 to 30 feet above all surrounding obstructions. As commonly constructed, this tower is supported on four inclined pillars which straddle the well, and on its top is built a platform or turntable with an open center through which the pump rod descends vertically to the reciprocating force pump in the well. Wooden towers of this form are built from 20 to 40 feet in height, with upright corner posts of 4 by 4 to 4 by 6 inch timbers, crossed-braced with 1 or 2 by 6 inch planks. The corner posts are usually firmly anchored and doweled into foot posts buried in the ground and made of 8 by 8 inch timber. Nailed to one of the side pieces is a ladder by which to reach the platform.

Windmill towers are now often built of angle steel varying in size from 2½ to 4 inches, according to the size of the wheel and height of

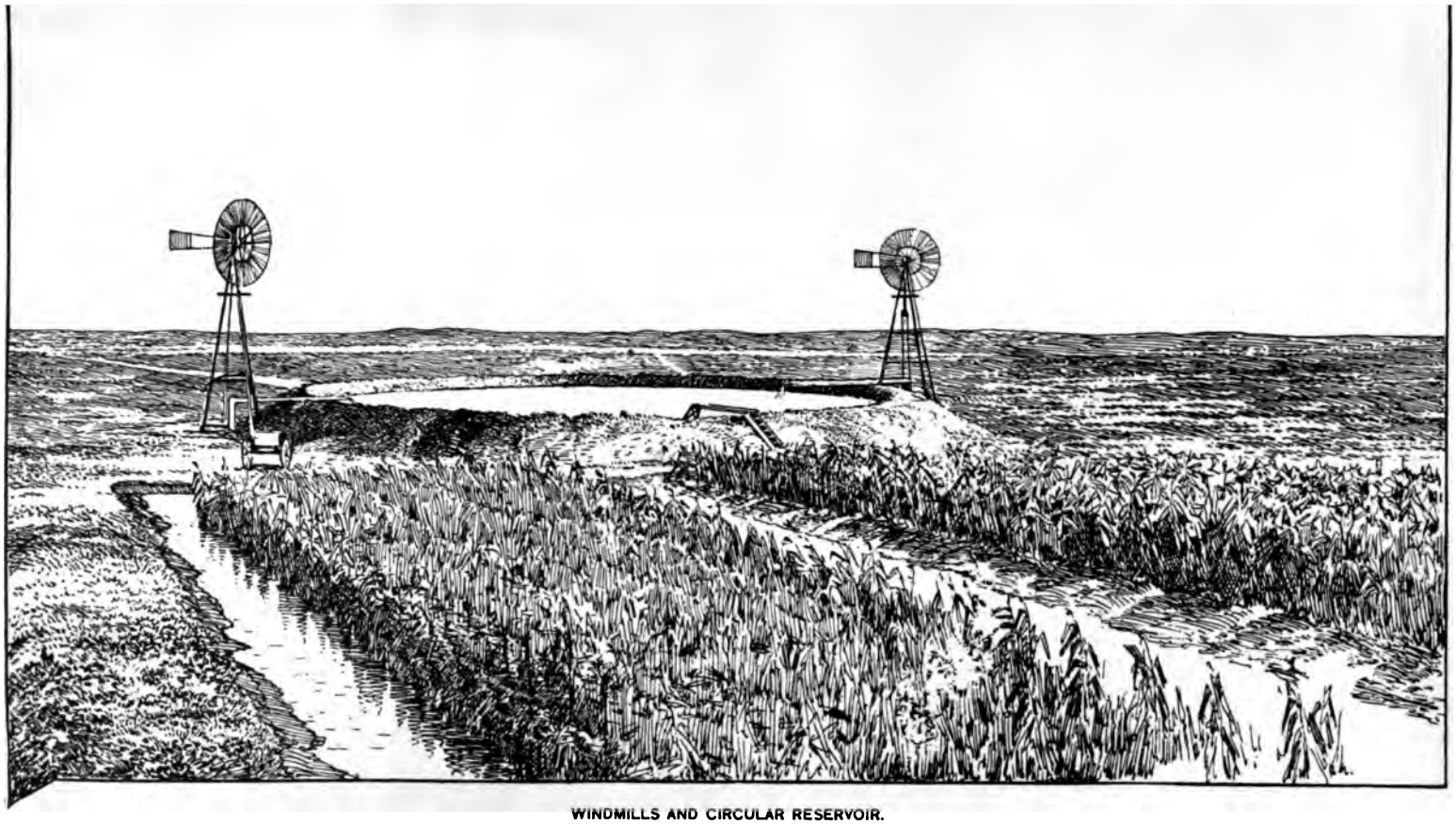
the tower. These are in form more graceful than the wooden towers, and more stable, since they offer less resistance to the wind, and if properly proportioned should outlast wooden structures and withstand heavier gales. In the illustration (Pl. II) one of these towers is shown supporting a tank above which in turn is the windmill, this arrangement being adapted for village or domestic supply, combined with irrigation. In order to secure pressure for the former purpose the water is pumped by the windmill into the vertical pipe leading to the tank, but at the times when it is used for irrigation the water is not lifted to this elevation, but is only brought to a short distance above the ground, being allowed to flow out into an open pond or reservoir from which it can be drawn to the fields.

These steel towers are built as high as 100 feet, and at comparatively little cost, so that there is no difficulty in raising the wind wheel well above all surrounding obstructions. A recent development of interest in the construction of such towers is a tilting tower. This is constructed in such a manner that the upper part carrying the wheel can be tilted or brought down to the ground in a few moments and with little exertion, permitting easy adjustment and oiling. Metal towers are usually anchored on heavy wooden posts, or preferably in masonry, where the latter is easily obtainable.

In erecting either wooden or steel towers care should be taken to keep them plumb and to place the pump rod directly over the pump. Above the platform the horizontal crank shaft is supported in bearings on the upper movable part of the turntable and is connected with the pump by a swivel joint, in order to permit of rotation of the mill top in making necessary adjustments of the sails to changing directions of the wind. An overhanging arm of the crank shaft carries the wind wheel. This, in some forms of mill, is on the lee side of the tower, in which case it maintains its direction perpendicular to the wind by pulling the turntable around, and is rudderless. In other forms the pressure of the wind on a rudder vane of sufficient area and leverage to overbalance the wind keeps it nearly perpendicular to the direction of the latter and on the windward side of the tower. Most mills have, in addition, a controlling or regulating gear by which they can be stopped when the reservoir is full or repairs are necessary, and to prevent damage during gales. This gearing may be either automatic or operated by hand.

There are many varieties of force, siphon, and patent pumps used in lifting water by wind power. It is impossible to say which of these is best suited for general service. The irrigator will do well to leave the selection of the pump required for his particular conditions to the windmill maker, for every manufacturer of windmills is prepared to supply any of the standard pumps and is sure to suggest that type and size which he believes will best meet the requirements, that it may make the best showing for his mill.

Windmills average in cost from $50 to $400, according to size and



WINDMILLS AND CIRCULAR RESERVOIR.

NORIA, OR WATER WHEEL, LIFTING FILLED BUCKETS.

make. Storage tanks or reservoirs may be built for $100 and upward. The pump worked by the wind wheel should be of the best make and of a diameter not less than 3 inches and thence to 8 or 10 inches, certainly of sufficient capacity to handle all the water which the wind wheel is capable of lifting. On an average a 5-inch pump will discharge 250 cubic feet an hour, a 6-inch pump about 380, and an 8-inch pump 650. On this basis, and with the average water duty, a 5-inch pump will therefore irrigate 6 acres if running constantly, or 2 acres if running one-third of the time. The average windmill will irrigate from 1 to 3 acres. If it is supplemented by ample storage facilities these figures may be multiplied by 3 or 4. In other words, it will irrigate from 3 to 10 acres. There are windmills of sufficient size in the West, where the wind is amply steady, to irrigate, with the aid of storage tanks, from 5 to 10 acres, pumping from wells 30 to 150 feet in depth. Theoretically, a 25-foot windmill working eight hours a day for one hundred and twenty days will pump 40 acre-feet to an elevation of 25 feet, and if storage capacity for half this volume be provided it will be capable of irrigating about 20 acres.

An excellent example of a windmill pumping plant is that of Mr. E. E. Frizell at Larned, Kansas, shown on Pl. III. This consists of three 14-foot steel windmills on 30-foot towers and discharging into a reservoir 130 feet in diameter, with banks 8 feet high. The pumps have 10-inch cylinders, and with a lift of 25 feet can fill the reservoir in about two days. The available capacity of the reservoir is nearly 2 acre-feet (Pl. IV), and in a season the plant is capable of irrigating 60 acres successfully. When the reservoir is filled a sufficient head of water is available to enable it to flow freely over any part of the irrigable area and in sufficient volume to thoroughly soak the soil.

WATER WHEELS.

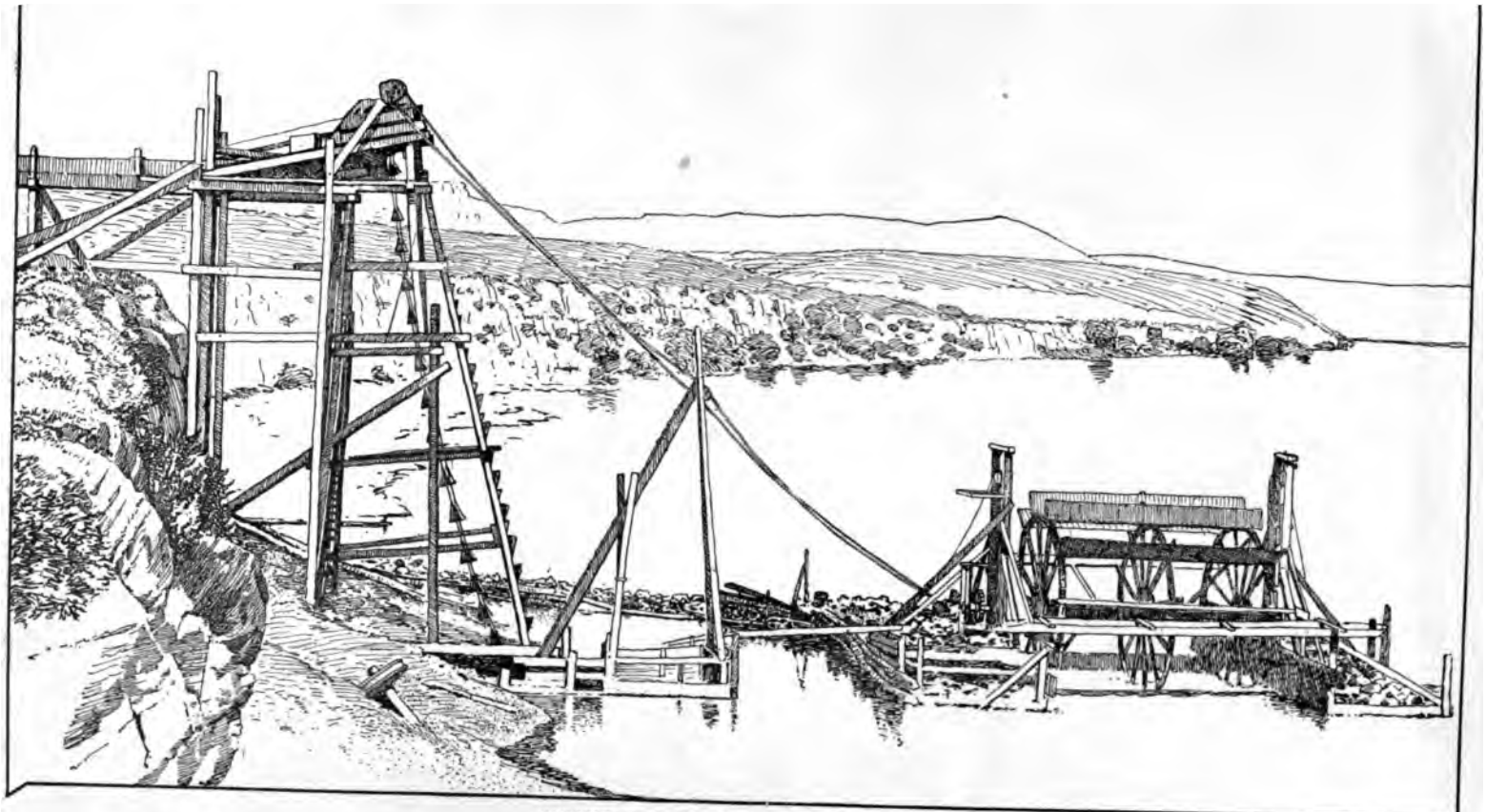
Water acts as a motive power by its weight or by its impulse. In the former case it falls slowly through a given height, and in the latter it passes through the motor with a constantly increasing velocity. Water motors may be divided into two classes, (1) water wheels and (2) water engines, each of which may be subdivided into several classes. Of water wheels the principal varieties are (1) undershot wheels, (2) breast wheels, (3) overshot wheels, (4) Pelton wheels, and (5) turbines. In addition there are water-pressure engines, rams, bucket engines, etc., but most of these are antiquated or not economical, and it is therefore hardly necessary to describe them as machines for elevating water for use in irrigation. Of these devices, however, rams are very economical where but a small volume is to be lifted.

In considering the subject of lifting water by means of water power, it may be said, as of other water-lifting machines, that the duty they have to perform may be the raising either of a large volume of water

to a small height or of a small volume to a large height. These duties may both be performed with a water power derived through either a large volume of water from a small height or a small volume of water from a great height. It is this intimate connection between volume and head of power and resulting work which calls for the exercise of discretion on the part of the irrigator in choosing the water motor best suited to his special requirements. A ram is nearly always called upon to utilize a large volume from a small height to raise a small volume to a great height. The Pelton water wheel generally utilizes a small volume from a great height to elevate varying volumes to varying heights. Undershot and breast wheels utilize large volumes from small heights to elevate moderate volumes to small heights.

Of undershot water wheels there are practically three varieties—midstream wheels, the common undershot wheel, and the Poncelet wheel. The midstream wheel is actuated by the velocity or impulse of a current of water in the middle of a broad stream in which it may be set. Such wheels are rarely employed, but when they are it is almost exclusively to raise water for irrigation. They are simple in construction and operation, and may be advantageously employed where water is abundant, even in streams having moderately low velocity. Such wheels produce the best result when their float boards or paddles are made straight, but not radial. They vary from 12 to 25 feet in diameter, their float boards varying between 10 and 15 in number, 2 of which should always be immersed at the same time. These project from 24 to 30 inches from the wheel rim, dipping into the water about one-half their depth. In rivers, the water levels of which fluctuate, the axle of the wheel is placed on movable supports, as shown in fig. 11, to render it capable of being raised or lowered at pleasure. An interesting adaptation of the midstream wheel for lifting water for irrigation is that illustrated on Pl. V, which represents such a wheel floating in the Colorado River, and by means of gearing and an endless cable, causing buckets attached to an endless chain to lift water from the river to the irrigating ditch above, a height of about 25 feet.

Numerous midstream wheels have been employed in the West for pumping irrigation water. They are almost always used as norias, having attached to their outer rims a number of buckets which dip into the water as the wheel revolves, and, as they reach the upper portion of their cycle, spill their contents into a trough which leads into the irrigation ditch (Pl. VI). Such wheels are of very ancient origin, having been used in almost every country in the world, most extensively, perhaps, in Egypt and Italy. Some very large wheels of this variety have been successfully employed on the Green River in Colorado. The diameters of these wheels are from 20 to 30 feet; they are hung on wooden axles 5 inches in diameter, and their paddles dip 2 feet into the stream. The buckets attached to their outer circumferences are of wood, having an air hole in the bottom closed by a suitable



MIDSTREAM WHEEL DRIVING A BUCKET PUMP.

NORIA, OR WATER WHEEL LIFTING FILLED BUCKETS

eather flap valve. These buckets are 6 feet in length and 4 inches quare, and have a capacity of two-thirds of a cubic foot each. The argest of them raises 10 cubic feet per revolution, and handles in all bout 4,000 cubic feet per day, or, approximately, one-tenth of an acre-ot. An apparatus not unlike the noria is the ancient wheel employed n Egypt and known as the tympanum (Pl. VII). This wheel is a com-ion undershot wheel turned by paddles dipping into a flowing stream, ut instead of lifting water in buckets, the water enters a series of piral gutters, and as the wheel revolves flows through these until it nally reaches the center of the wheel near the hub and passes out at is point into the irrigation ditch.[1]

Common undershot water wheels are better than midstream wheels here a fall of sufficient height to give a good velocity can be obtained. hese are placed in a channel or mill race of about the width of the heel, but a little wider at the inlet than at the wheel. The paddles

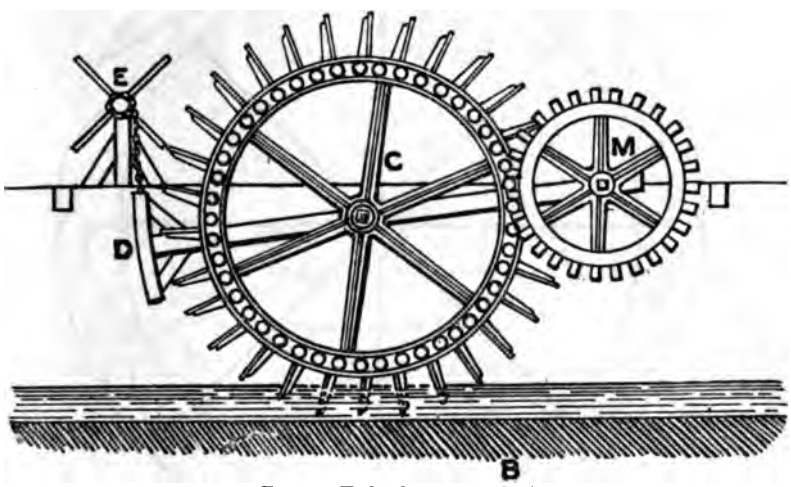


FIG. 11.—Undershot water wheel.

re similar to those of midstream wheels, though they are sometimes urved and of iron (fig. 11). They vary in diameter from 10 to 20 feet nd have usually from 30 to 40 paddles of from 1½ to 2½ feet in depth nd with face lengths of from 2 to 6 feet. In the illustration, fig. 11, a simple form of undershot wheel is shown, diagrammatically, exhibiting a common method by which the wheel can be raised or lowered to suit the fluctuating height of the stream. The axle of the paddle wheel (C) is supported at about the middle by heavy timbers (D), the ends of which on the downstream side are pivoted in line with the axle of the wheel (M), which transmits the power. The upstream ends of the timbers are hung on chains passing over a windlass (E), by which the timbers can be hoisted or lowered, thus adjusting the height of the paddles. Greater

[1] A form of wheel similar to this, carrying the water through curved pipes instead of rectangular compartments, is illustrated in the Scientific American of September 5, 1896, page 17.

efficiency can be obtained from undershot wheels if the paddles are m concave or of the type known as Poncelet. These latter are immer nearly to the height of their axle, the water being partially scree from them by a curved breast-piece or apron, so that the current pinges against the curved blades somewhat in the manner of the act in a turbine.[1]

Overshot wheels are economical in their use of water, and are th fore employed where it is scarce. In these the water is delivered ab

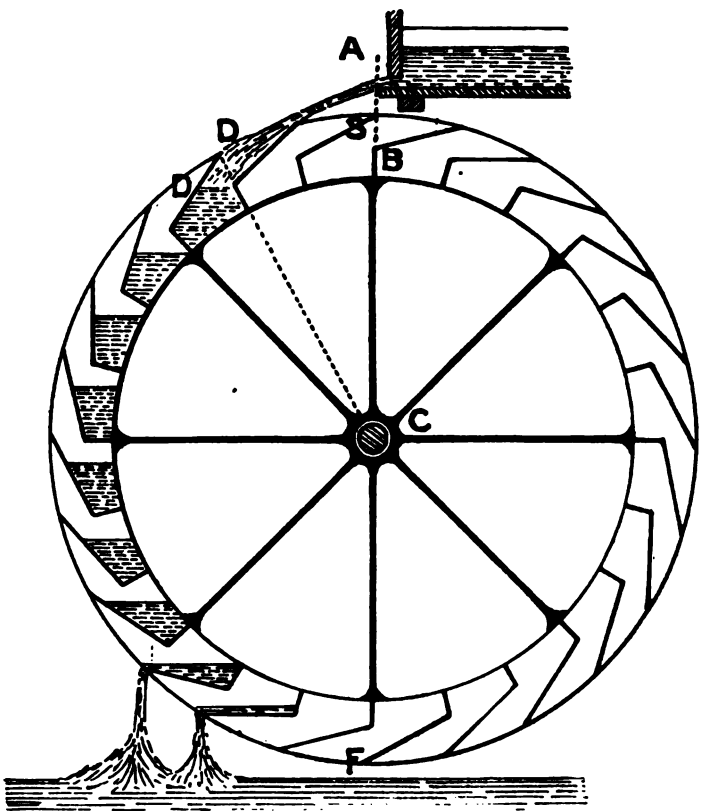
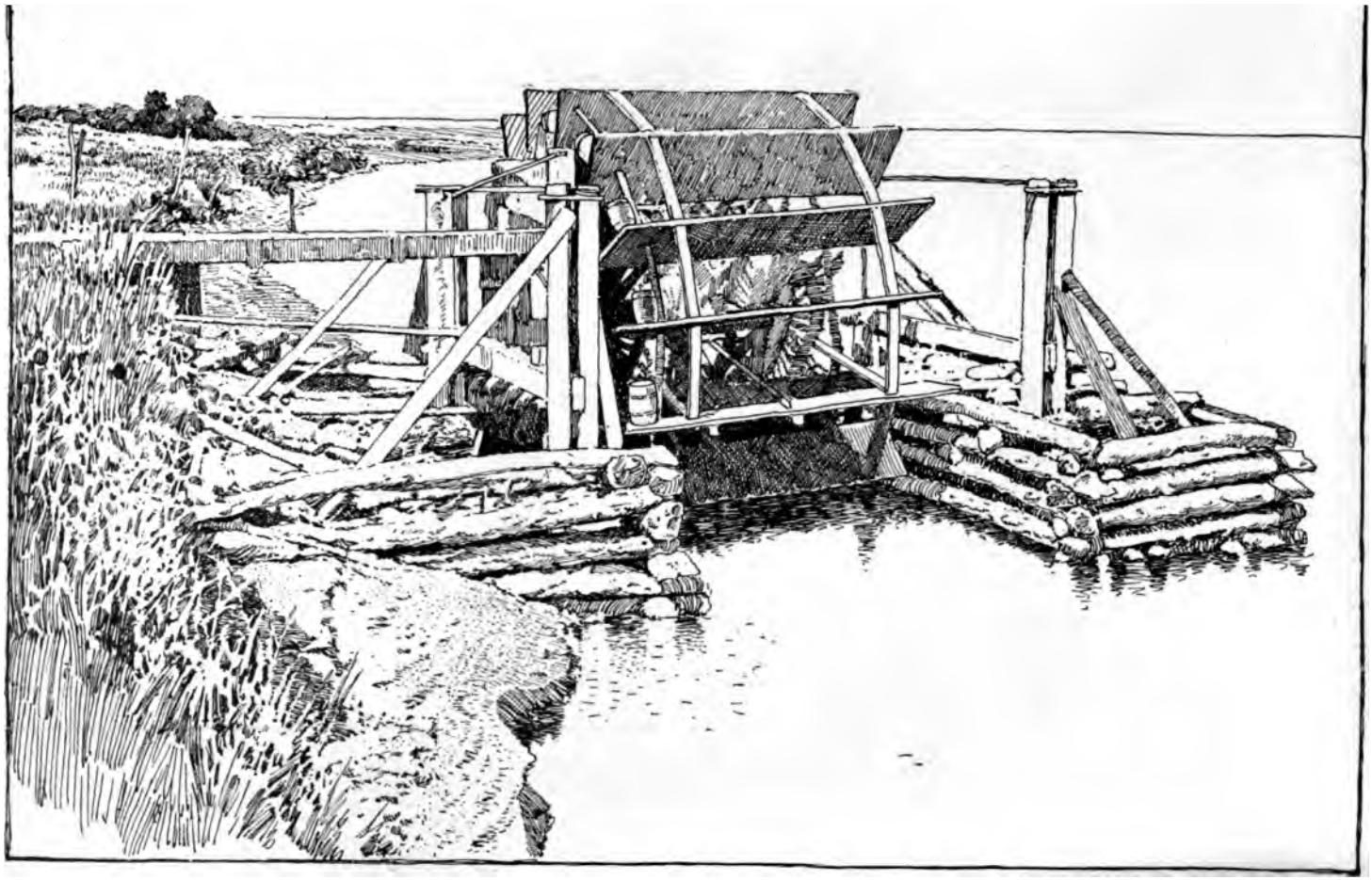


FIG. 12.—Overshot water wheel.

the wheel by means of a flume, mill-race, or penstock, and they are constructed that the water may be thrown upon either the near or far side of the wheel, according to the arrangement of the outlet ga controlling the supply. On the outer circumference of the wheel i series of buckets of the full length of the wheel face. Into these buck the water pours, and by its weight carries the wheel down, causin to revolve (fig. 12). As it turns, each bucket (D D) fills in passing

[1] The Mechanics of Engineering and of Machinery, Weisbach and Dubois, Vol. 2; John Wil Sons, 1889, page 316.



inlet orifice (A) and empties as it approaches the outlet channel, so that on one side are always a certain number of filled buckets. Such wheels may be employed to utilize falls of from 6 to 60 feet. In order to lose as little of the fall height as possible, the bottom of the wheel should approach close to, but not dip into, the lower water surface. The greater the width of the faces of these wheels the larger volume will their buckets hold, and, accordingly, the greater power will they exert. Overshot wheels may be employed to operate, through gearing or belting, any of the usual forms of reciprocating, centrifugal, or force pumps, and they will elevate volumes of water to heights proportional to the power which they are capable of developing. The largest, and therefore, perhaps, the most interesting, overshot wheel ever constructed is on the Isle of Man. The diameter of this wheel is 72 feet and 6 inches, and it is claimed to develop 150 horsepower, which is transmitted several hundred feet by means of wooden trussed rods to a series of pumps capable of raising about 33 cubic feet of water per minute to a height of 1,200 feet.

Turbines are horizontal water wheels and may be classified according as they are acted upon—(1) through impulse, (2) through pressure, or (3) through reaction. Impulse wheels have plane or concave vanes or float boards on which the water strikes more or less perpendicularly. Pressure wheels have curved float boards along which the water glides. Reaction wheels are actuated by an arrangement of pipes from which water issues tangentially. To this latter class belong Pelton and other forms of tangential wheels. Pressure and reaction wheels, though similar in construction, differ in that in the former the passages between the vanes are not completely filled with water, while in reaction wheels the water fills and flows through the whole section of the discharge pipe. Turbine wheels are again subdivided into the following three classes: (1) outward flow, (2) inward flow, (3) mixed or parallel flow, the latter really combining the first two classes. Outward-flow turbines receive the water at the center and deliver it at the periphery of the revolving wheel. Inward flow turbines act in practically the reverse manner from that of outward-flow wheels.

Turbines possess an advantage over the older types of wheels in that they may be used with any fall of water, from one to several hundred feet. They have many other advantages over such water wheels; they may be regulated according to the power required and the water supply available, the regulating apparatus being such that the efficiency remains nearly the same, whether water is scarce or abundant. Again, turbines may be submerged, while other forms of water wheels must be elevated above the tail-race. The turbine takes its supply at the bottom of the fall, while overshot water wheels take it from the top of the fall, thus the former utilizes practically the whole height of fall. Furthermore, turbines move with a greater velocity than vertical water wheels, and hence may be materially reduced in size and weight for an equal

production of power. In fig. 13 a turbine is shown geared to a centrifugal pump, as employed in irrigation.

There are a number of successful forms or types of turbine water wheels made in this country. The advantages of each of these are fully described in the trade catalogues of the various makers, and much additional useful information relative to them can be obtained by the prospective irrigator through correspondence with the manufacturers. In the West are a number of irrigation pumping plants operated by turbines. The wheels range in size and power from a few inches in diameter, operated under but a few feet of head, and developing a fraction of a horsepower, up to enormous engines rivaling those recently built for utilizing the fall of Niagara, capable of producing as much as 2,000 horsepower each, and operated under several hundred feet of head, their

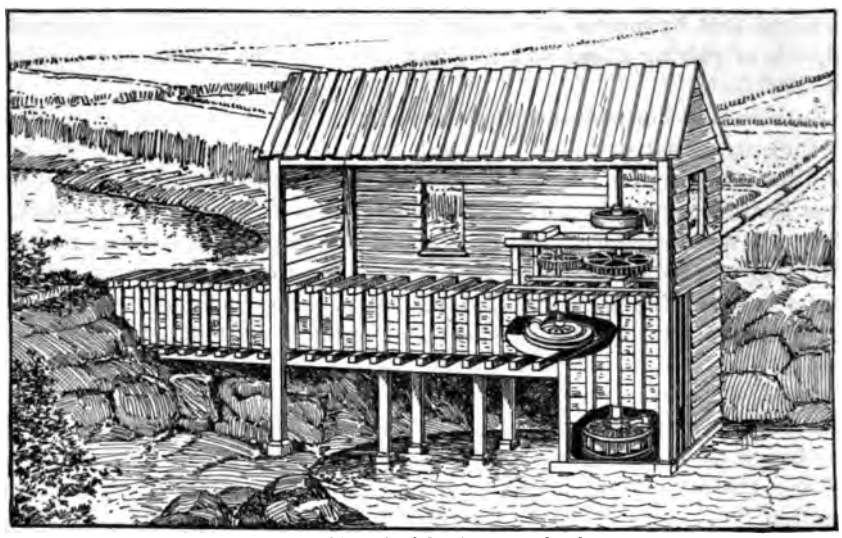
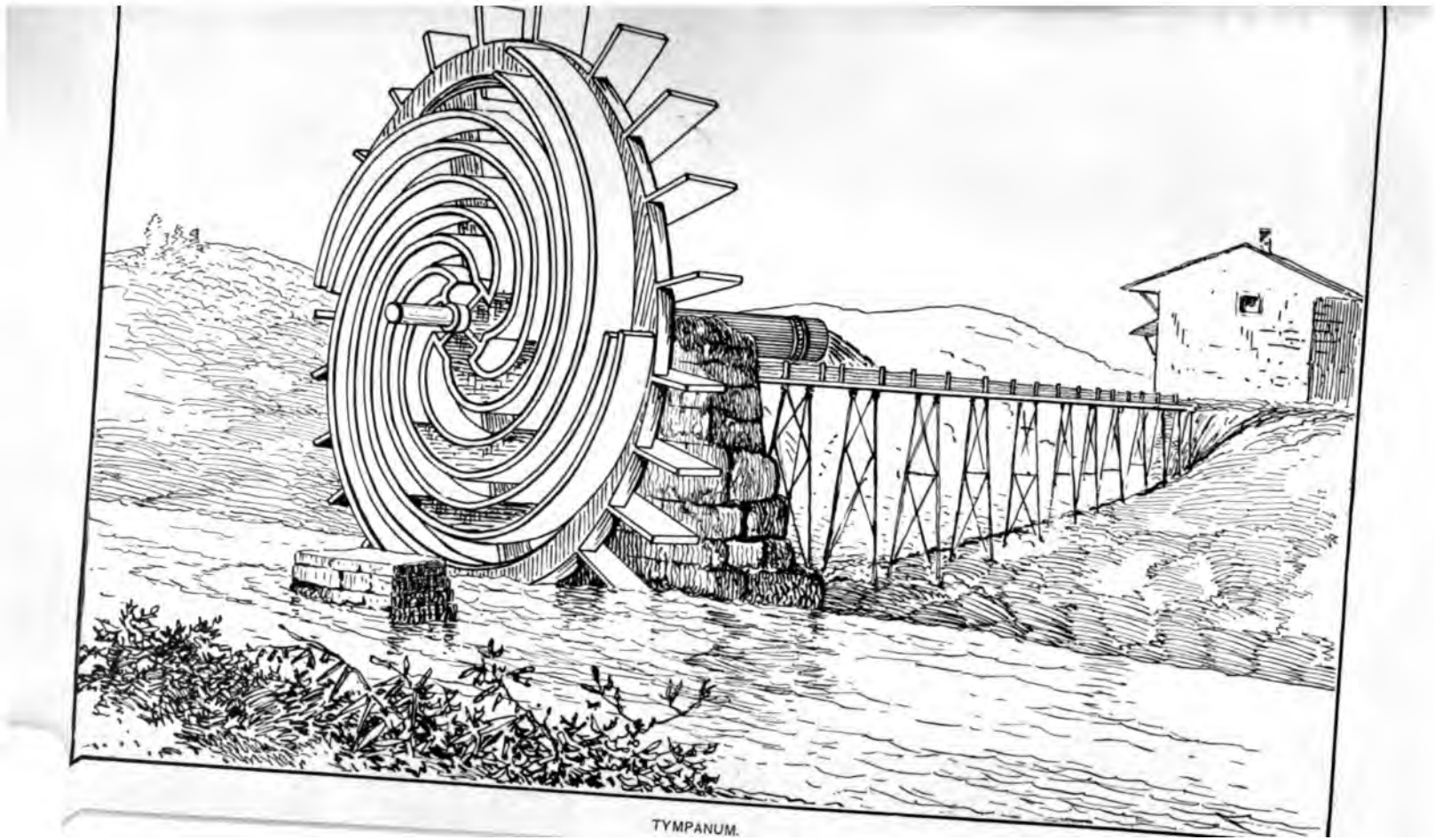


FIG. 13.—Turbine wheel driving centrifugal pump.

diameters being as great as 6 to 8 feet. They range in price, likewise, from $100 to several thousand dollars. There has been recently erected at Prosser Falls, Washington, a turbine power and pumping plant capable, it is estimated, of irrigating 4,000 acres besides furnishing power for factories and other purposes. This plant pumps water to an elevation of 100 feet, with a power-producing fall of 20 feet. There are two turbines, each 48 inches in diameter, and each capable of developing 135 horsepower under a 12-foot head. Each operates a duplex pumping engine of 25-inch cylinder and 24-inch stroke, each having a capacity of 4,000 gallons a minute.

Tangential water wheels are simpler in construction than turbines, less liable to get clogged or out of order, and they may be worked under much greater heights of fall than other forms of water wheels. They derive power from the impulse of water discharged from a nozzle



TYMPANUM.

kets on the lower side of the wheel (fig. 14). They do not work sfactorily as turbines with heads less than 30 feet, though they :e small powers with great efficiency at even lower heads. But 50 feet and up to 2,000 feet there is no other water wheel so effi- is the tangential. It has a wide range of adaptability to varying ions of water supply by simply changing the nozzle tips. As ckets are open, there is no uncertainty from derangement of or stoppage by driftwood. They are relatively cheap of instal- and admit, by varying their diameters, of being placed directly crank shaft of power pumps without intermediate gearing. The is the most common form of tangential wheel.

Pelton wheels have yet been employed in pumping water for ion, but as they become better appreciated it is probable that 'alue in utilizing small volumes of water from great heights will

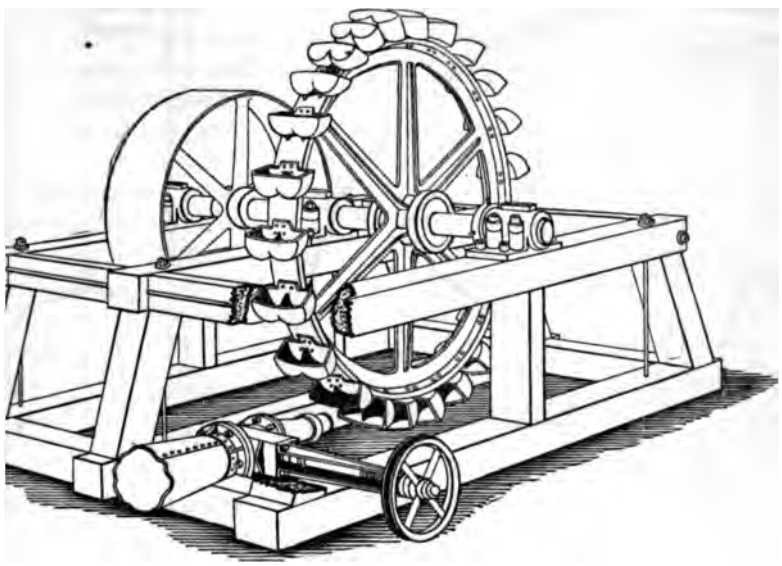


FIG. 14.—Pelton water wheel.

them more popular. Pelton wheels are made of varying sizes, hose capable of developing a fraction of a horsepower from the supply of a house faucet or mountain spring to the largest size. ecently constructed for the North Star Mining Company, Grass , California, operated under an effective head of 750 feet, is 18½ n diameter and of 300 horsepower capacity. This wheel is ed on a bicycle-spoked frame having a 10-inch steel shaft. Its eral speed is 6,000 feet a minute, and its efficiency is about 90 per Another Pelton wheel working under 810 feet head is but 40 in diameter and develops 600 horsepower.

re is now being made by the Austin Manufacturing Company, of go, an apparatus called the Improved Current Motor, the object

of which is to develop power from the water flowing in a large stream something in the manner in which it is developed by the ordinary undershot water wheel. This apparatus consists of a narrow, floating, scow-shaped pontoon, a sort of floating platform, about 100 feet in length by 11 feet in width. The upstream end of this is pointed like the prow of a boat, that it may part the current of the stream. This float is anchored in midchannel and carries a couple of endless chains running over sprocket wheels 5 feet 6 inches in diameter hung on 2-inch shafts. These sprocket wheels are situated at each end of the pontoon, and the endless chains bear between them, at intervals of 8 feet, float boards 6 feet 10⅜ inches in length by 3 feet in depth. These float boards are acted upon by the current, which carries them along beneath the pontoon, over the rear sprocket wheel, whence they return above the platform to the front sprocket wheel and again pass into the water. The power developed by this motor is transmitted by belting and gearing to an ordinary endless chain carrying buckets or other mechanical water elevators (see p. 51) which lift the water from the stream into the irrigating canal.

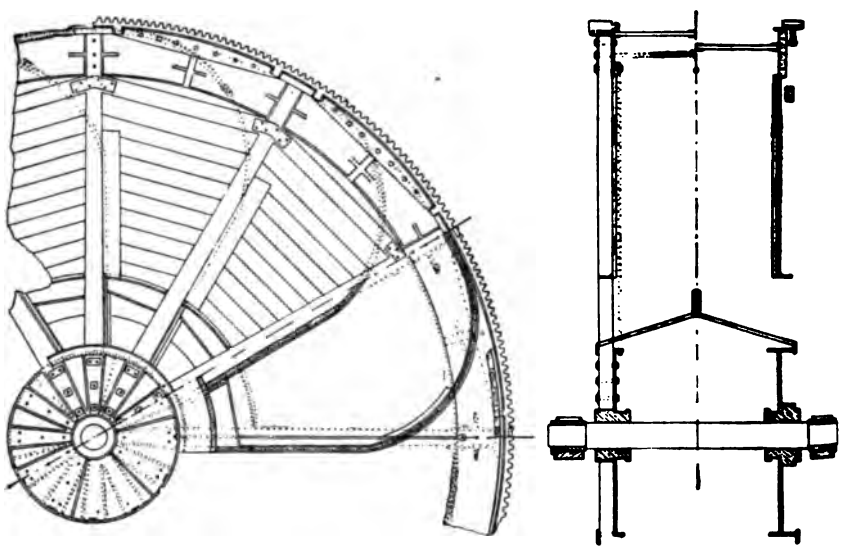


FIG. 15.—Wheel for lifting water on Chesapeake and Delaware Canal.

A curious and at the same time interesting form of water wheel, which is not a water motor, but is used to lift or pump water, is one which is employed on the Chesapeake and Delaware Canal to elevate water from a lower to a higher level. This wheel (fig. 15) is similar in its mode of operation to the tympanum of Egypt, shown on Pl. VII. It is 39 feet in diameter, 10 feet in width on the outside, and 7½ feet on the inside. Of its face width 24 inches is occupied by two bands or rows of heavy iron cogs, which bind the outer edges of the wheel.

This revolves on a 15-inch iron axle, reduced at the bearings to 12½ inches, and is turned by a couple of cogged pinions, each 4 feet in diameter, mounted on a 12-inch crank shaft. These pinions gear into the cogged bands on the outer edges of the wheel. The shaft bearing the cogged pinions is connected directly, through cranks, with two large low-pressure condensing beam engines. These engines have each 7-foot stroke and 36-inch cylinders, and are each capable of developing 175 horsepower, or a total of 350, on a consumption of 900 pounds of coal per hour. The central portion of the wheel, 8 feet in width on the face between the cogged bands, is divided into twelve openings, each about 18 inches wide at the mouth, and these are the entrances to spirally curved buckets of the full width of the wheel, which enlarge as they approach the center and then diminish at their inner or discharge orifices to a width of 2 feet. Surrounding the main axle is a conical wooden hub, from 8 to 11 feet in diameter, so designed that the water falling on it from the buckets is thrown in either direction and empties into two canals, one leading away from each side of the wheel, discharging a little beyond into the main canal. The buckets terminate within 4 feet of this central hub, and have an inside depth along the diameter of the wheel of 12 feet. As the wheel revolves, the buckets fill by immersion in the feeder canal, and the water falls out at the lower end of these buckets onto the hub and thence into the out-take canals. The lift from the surface of the feeder canal to the surface of the out-take canal is 14 feet. The wheel makes 100 revolutions per hour, and is capable of lifting 300,000 cubic feet of water per hour to this height. This is equivalent to about 170 acre-feet of water per day of twenty-four hours, or about 83 second-feet flowing continuously. This, on a consumption of about 10 tons of coal for twenty-four hours at $5 per ton, or $50, is equivalent for fuel alone to a charge of about $1.30 per acre-foot. The efficiency of this machine seems to be relatively so high as a pumping machine for low lifts and large volumes that it is not improbable that it may be found advantageous to employ some such apparatus in irrigation.

Hydraulic rams may be utilized where there is a trifling fall and but a small amount of water is to be lifted. They work on the principle of a large volume of water having a small fall forcing by impulse blows a smaller volume to a higher elevation. Water is delivered to the ram from a reservoir or stream with steady flow through the supply or drive pipe. At the end of this is a check valve, opening into a chamber connected with the discharge pipe. As the water passes through the drive pipe it flows, with a velocity due to its height of fall, through a weighted pulse or clack valve which opens inward. It almost instantly closes this valve, and at the moment the issue of water ceases a ramming stroke is created which opens the delivery valve and permits the water to enter the air vessel, and at the same time, because of its velocity, the water flows back through the drive pipe. At the instant the backward flow begins the delivery valve closes and the pulse valve opens

to allow the passage of the water from the supply pipe, and the operation is repeated. In general, it may be stated that a hydraulic ram will elevate one-seventh of the supply volume of water to a height five times the fall, or one-fourteenth part to ten times the height of fall. The fall should range from 2 to 10 feet, but not more. Hydraulic rams are very cheap, both to purchase and to maintain, and are unaffected by tail water, as they will continue working even when flooded. It may be stated that in placing a hydraulic ram the length of drive pipe should be increased as the height to which water is lifted is increased, so that water shall not be forced back in the drive pipe as the pulse valve closes. The length of the drive pipe should in general be five to ten times the height of fall. The delivery pipe is usually from one-third to one-fourth the area of the drive pipe.

Of the many types of hydraulic rams in the market but few are of

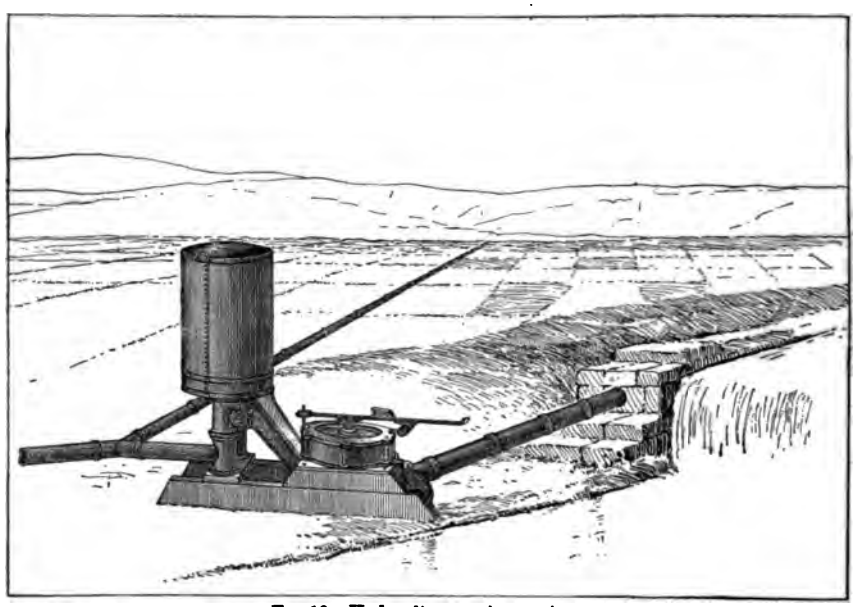


FIG. 16.—Hydraulic ramming engine.

sufficient capacity to perform the amount of work required in supplying irrigation water. Those which are capable of performing this work partake chiefly of the nature of hydraulic ramming engines, and are constructed somewhat differently from rams proper. They may be actuated by dirty as well as clear water, but are more intricate in their construction than are simple rams. One of the most effective of these engines is the Rife hydraulic ramming engine (fig. 16). This is said to be capable of elevating water to a height of 25 feet for every foot of fall, and to deliver one-third of the water used in operation to two and one-half times the height of fall, or one-sixth of the water to five times the height of fall. Only the largest of these are capable of elevating enough water for irrigation. Those having a drive pipe 8 inches and a

delivery pipe 4 inches in diameter are capable under a head of 10 feet of elevating about one-half of an acre-foot per day of twenty-four hours to a height of 25 feet. Such a machine costs $500, or at the rate of about $10 per acre irrigated.

HOT-AIR AND GASOLINE PUMPING ENGINES.

These machines have been extensively used in the East for pumping moderate quantities of water for domestic consumption and for small factories or villages. Lately they have been successfully employed in pumping small irrigation supplies in the West, and are undoubtedly destined soon to gain popular favor, chiefly because of their simplicity, economy, and the ease with which they can be stopped and started and maintained in successful operation by unskilled labor. Hot-air pumping engines do not depend for their operation on power developed by the expansion of steam to convert heat into motion. Gasoline engines are likewise operated without converting the heat into steam, but by the expansive force produced by the explosion of vaporized gasoline when ignited in contact with air. Both of these types of engines are made only to develop comparatively small powers, and therefore are utilized in pumping but comparatively small volumes of water, usually irrigating from 5 to 50 acres. These engines have decided advantages over water and steam motors in that they can be employed where there is not sufficient water supply to operate a water motor and because of the kind of fuel which they consume, gasoline engines being serviceable in arid regions where fuel is expensive and difficult to obtain, and hot-air engines being capable of utilizing almost any variety of fuel. Moreover, these engines are small and compact, simple of erection by comparatively unskilled labor, and may be operated with the minimum expense for supervision and with little skill on the part of the operator.

Hot-air engines are constructed almost wholly for pumping purposes, the motive power and pumping apparatus being combined in one machine inseparably connected in one frame. They are so simple in operation that anyone capable of lighting a match may run them. There is no possibility of explosion, and when once started they require no further attention than for replenishment of fuel. They are made in capacities ranging from a few gallons per minute to one-tenth of a second-foot, equivalent to two-tenths of an acre-foot per day of twenty-four hours, limited by the height of lift, which varies from a few feet to 500 feet. The chief objection to hot-air pumping engines is their great first cost, which for the larger size is $600, or $6,000 per second-foot, equivalent to about $100 per acre irrigated.

Gasoline engines are used extensively in some portions of the West, notably in Kansas, for pumping water for irrigation. They are made of various dimensions, up to those capable of developing 50 horsepower and pumping a correspondingly large volume of water, and they are

constructed as combined motive and pumping plants or as separate motors to be attached to varying forms of pumps. The chief advantages which these machines have over other motive powers for pumping are their compactness and simplicity of installation and operation, and, above all, their cheapness, not so much for first cost as for ultimate maintenance, though in this latter item they do not surpass hot-air pumping engines. The largest of these engines are capable of elevating for low lifts as much as 3 second-feet of water, or 6 acre-feet per day of twenty-four hours, and lesser quantities to greater heights in proportion. The cost of operation of such a machine as this has been asserted to be for gasoline as low as $1.25 per day, or 20 cents per acre-foot. It is stated that these engines will pump water at a cost of about 1 cent per hour; and working ten hours a day, the largest size will elevate sufficient water to a height of 20 feet to irrigate about 320 acres if storage be provided. The first cost of the plant is from $400 to $600 for engines capable of irrigating 10 to 20 acres, and larger plants in proportion. This is at the rate of about $30 per acre without storage, and the cost of operation is about $1.25 per acre irrigated.

STEAM PUMPING ENGINES.

Of the many forms of motors utilizing steam power, the following two classes cover most of those which are of interest to irrigators: (1) those which utilize steam power by indirect transmission to the pump through gearing, belting, or other separable connection; (2) those which utilize steam power through an engine directly coupled with the pump, as direct-acting or fly-wheel pumping engines. It is not desirable to refer here to the many forms of steam engines and boilers employed in developing steam power for actuating plunger, centrifugal, or other pumps. They are innumerable and are manufactured in all varieties, forms, and sizes and at all prices. The irrigator must determine by consultation with makers of steam engines and boilers those which are best suited to the work which he has to perform. On the other hand, direct-acting engines, being inseparable from their pumps, may be here considered, as each differs not only in its motive power but in its pumping mechanism.

In endeavoring to determine the power required of a pump that it may elevate a given volume of water to a given height the same considerations must be dealt with as in transforming power developed by windmills or water motors into volumes lifted to given heights. This may be roughly stated by the formula: horsepower required, H. P., equals time of work in minutes, t, multiplied by volume of water in cubic feet, r, multiplied by weight of a cubic foot of water ($62\frac{1}{2}$ pounds), w, divided by 33,000 pounds, the result to be multiplied by the height to which the water is elevated in feet, h, plus the resistance due to friction in pipes, f.

$$\text{H. P.} = \frac{62\frac{1}{2}\, t\, r}{33{,}000} \times h + f$$

The frictional resistance to flow is an indefinite quantity which may

e most easily determined by reference to such tables as Trautwine's or thers giving fractional resistance for pipes of given diameters and engths.

Direct-acting steam pumping engines differ from other steam pumps n that the motor and pump are combined inseparably in one mechan-sm, the power which performs work being derived from an ordinary team boiler, not through an engine separately geared or belted to the ump, but directly from pump plungers which form part of the steam iston or connecting rod. Such direct-acting pumping engines may be ither single or double acting. They have the water and steam ends entered in one line, so that the water plunger and steam piston are ttached to the same piston rod and work together without an inter-ening crank or other connection. This is the simplest and most com-act form of steam pumping apparatus, and is more extensively used or pumping than all other varieties of pumping machinery combined, hough it is, perhaps, one of the most wasteful and expensive forms of team engines. It is undoubtedly the most substantial and satisfactory orm of steam pumping apparatus for lifts exceeding 20 feet, for it is ess liable to derangement or accident and better fitted to perform con-tant, hard work than any of the separable steam engines and pumps. Iachines of this class are manufactured by many establishments, and he qualities and efficiencies of the various makes are well established y competition and experiment. Steam pumping engines are similar n nearly all the various makes, differing chiefly in details of valve notion. Among the best of these are the Knowles, Blake, Smith-'aile, Dean, Cameron, Worthington, and Davidson valve movements.

In selecting steam pumping engines, among the points most desirable re strength and simplicity of working parts, large water-valve area, ng stroke and ample wearing surfaces, continuity of flow, simplicity of djustment and repair, and moderate steam consumption. In choosing om the various makes of pumping engines it is well in correspond-ng with their makers to inform them, among other points, of the pur-oses for which they are to be used, height of lift and height to which ater is to be forced, quantity of water to be elevated, motive power, nd quality of fluid, as clear or muddy.

Direct-acting steam pumping engines may be either high-pressure or ompound. The latter are economical in both fuel and water consump-ion, and their cost for operation is correspondingly less, though their irst cost is a little greater. The best form of direct-acting are the luplex pumping engines, consisting of two direct-acting steam pump-ng engines of equal dimensions, side by side on the same bed-plate, vith a valve motion so designed that the movement of the steam piston f one pump shall control the movement of the slide valve of its oppo-ite pump so as to allow one piston to proceed to the end of the stroke nd come to rest while the other piston moves forward on its stroke.

All single-acting pumps should be provided with air chambers.

These are often an improvement even to double-acting pumps, for though the latter have a fairly steady discharge, the air chamber insures almost perfect uniformity of delivery. The capacity of an air chamber for a pair of double-acting pumps is about five or six times the combined capacities of the water cylinders, while for a single-acting pump it may be ten or twenty times greater. The air chamber performs practically the office of a stand-pipe attached directly to the pump. It neutralizes the variations of velocity of discharge in the delivery pipes, the fluctuations of which might cause danger of ramming and wastage of work. The air chamber obviates this by permitting the excessive delivery of water from a pump stroke to enter it and thus compress the air, while on the return stroke the expansion of the air forces out water to supply the deficiency.

Several extensive steam pumping plants have been employed in the West for providing water for irrigation. The first cost is usually a little greater than for centrifugal pumps, though not always so, depending upon the height of lift. Their efficiency is usually quite high as compared with all other forms of pumping plants, and their maintenance cost is usually less than that for centrifugal pumps. Their operation requires skilled labor, as does that of centrifugal pumps; but they are less liable to get out of order, and any injuries sustained can usually be readily repaired.

In Arizona is a high-pressure pumping engine capable of irrigating 100 acres per season which cost when erected $1,000, or $10 per acre irrigated, while the cost of running it is but $5 per acre. A larger and more modern plant operated near Tucson consists of two compound Smith-Vaile pumping engines, capable, it is claimed, of irrigating 600 acres per season at a cost for operation of $3 per day, the first cost for this plant laid down having been $4,200, and the height of lift being 70 feet. Still another pumping plant, consisting of an automatic cut-off condensing engine with two 150-horsepower boilers, has been erected on the Yuma River. The pumping engine has 18-inch stroke and 42-inch cylinders, and is of 165-horsepower capacity. This is an Allis pumping engine, having a fly wheel weighing 7 tons and making 67 revolutions per minute, the capacity of the pump being 12 second-feet, or about 24 acre-feet in a day of twenty-four hours. This pump delivers water through a 26-inch redwood stave main, elevating the water 80 feet, and this is stored in a reservoir having 23 acre-feet capacity. A year's test of this engine, according to the claims of the owners, shows it to be capable of discharging 12 second-feet at a cost of $3 per second-foot for fuel.

There has recently been erected at Eureka, Kansas, a pumping plant for the irrigation of about 3,000 acres. This consists of two horizontal return tubular boilers and two compound, duplex, direct-acting steam pumping engines of a maximum capacity of 530,000 cubic feet, or about 12 acre-feet per day of twenty-four hours, equivalent to 6 second-feet,

h a total lift of 65 feet. The cost of this plant, exclusive of the rage reservoir, was about $8,000, while the cost for operation is esti- ted to be $1.60 per acre, assuming that the full area is covered.

In addition to the better-known forms of steam pumping engines, ere have been built a number of patented types of pumps, gotten with the special view of lifting large volumes of water to small evations for use in irrigating or in draining lands. Three of the more otable of these are the Huffer and Nye irrigating pumps, formerly ade in Colorado, and the Menge irrigating and drainage pump, made New Orleans. The Nye pump is a curiously compact affair, worked irectly from a steam boiler in such manner as to utilize atmospheric ressure in producing power through condensation of steam. It re- uires little steam pressure except for lifts above those made by an tmosphere, say over 25 feet at sea level. It consists of two large ylinders fastened vertically on one bed-plate. Steam is let into one of hese and is instantly condensed by a spray of water, thus creating a acuum or suction power nearly equal to atmospheric pressure, and the ylinder is filled with water. As one cylinder is being filled the other being emptied, and at the same time receives steam for a similar con- ensation and vacuum. The action of the steam valves is automatic, nd steam enters but one cylinder at a time. These engines have no pis- ons or packing to wear out and practically no loss of power by friction; ney are simple in construction and erection, and little skill is required placing or in operating them. They are made of varying sizes, the rgest being capable of lifting nearly 7 second-feet of water to an ele- ation of 20 feet, and costing about $1,000, equivalent to a first charge r plant of about $140 per second-foot.

The Huffer pump works on a principle similar to that of the Nye mp, but while the latter is capable of forcing water to a height of early 100 feet by direct steam pressure, the Huffer pump is merely an tmospheric lifting pump, capable of raising water only to such height s the aid of atmospheric pressure will permit. The largest sizes of is pump are capable of lifting about the same volume of water as are ie Nye pumps. Neither of these pumps has met with popular favor, iiefly because they are not economical motors. In consequence, their anufacture has been discontinued.

The Menge pump has been most extensively employed in pumping ater from swamp lands or in lifting water to flood cranberry and rice vamps. Only recently have any of them been used for irrigation, and ien only for low lifts, usually between 5 and 10 feet. Above the latter eight a two-story or double lift may be employed, but is not quite so conomical. For the lower lifts which are within the power of one mp this machine is considered one of the most economical made. It a combination of wood and metal, and is operated by a stationary igine, belted to a pulley on a vertical shaft set in an upright wooden ox. The upright box has two suction ports at the lower end, midway etween which is the water wheel, from each blade of which is a free,

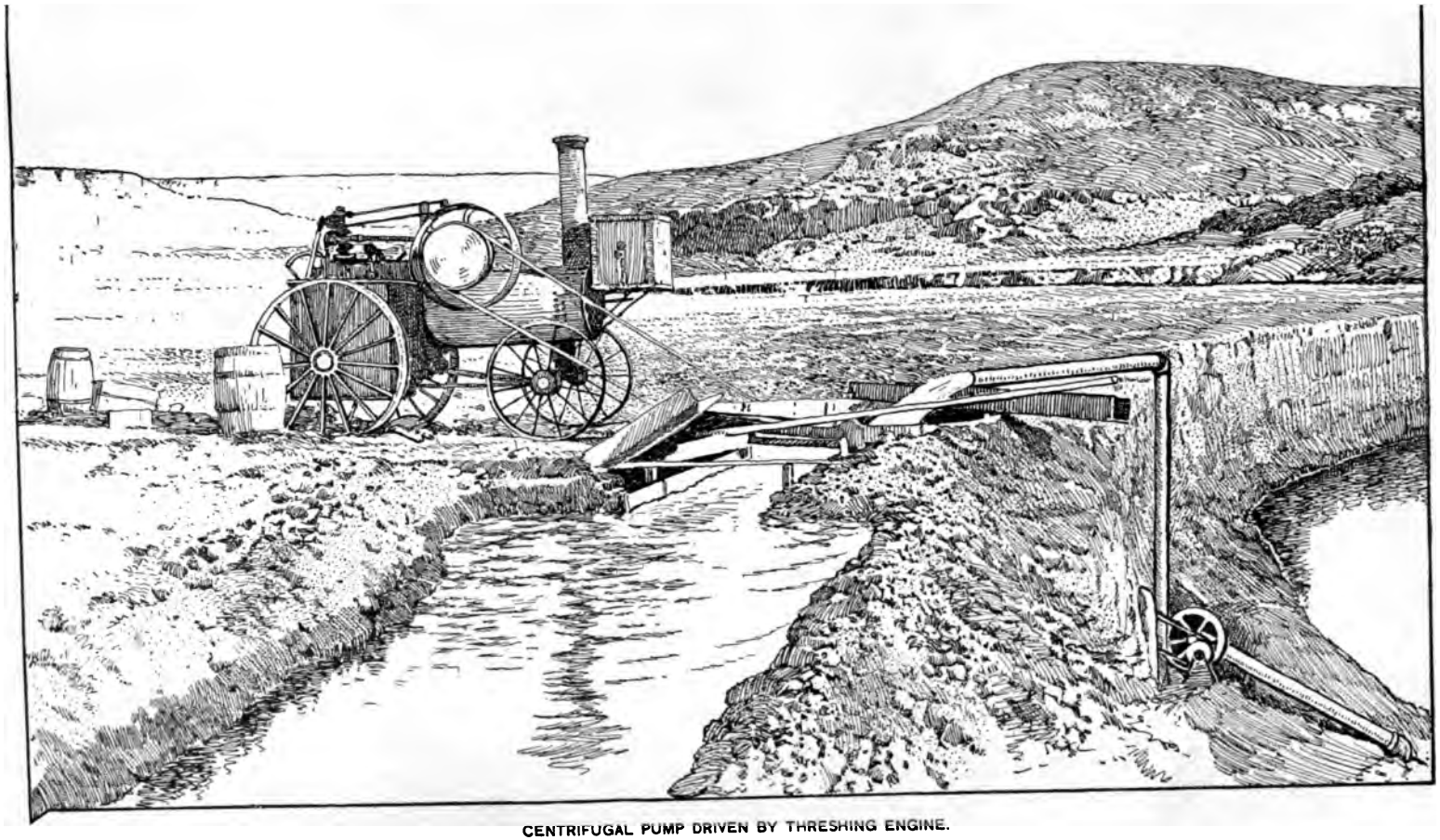
continuous delivery of water, which rises in the vertical box to the discharge outlet. These wheels are made in various sizes, from those which are but 4 by 8 inches up to wheels as great as 16 by 42 inches. The largest of these is claimed to be capable of lifting about 70 second-feet of water, equivalent to about 140 acre-feet per day, to a height of 10 feet on an expenditure of about 100 horsepower. The price of the Menge pump is exceedingly low, about $1,000 for the largest size, equivalent to a first charge for plant alone of approximately $14 per second-foot, plus the usual cost for steam boilers capable of producing this number of horsepower.

CENTRIFUGAL AND ROTARY PUMPS.

For lifting large volumes of water to moderate heights the centrifugal pump (fig. 13, p. 40) is most economical and efficient, as well as simplest in construction and cheapest in first cost of plant and erection. It is not, however, so substantial as a direct-acting steam pumping engine, and therefore not so suitable for large permanent works requiring considerable lifts. Where circumstances are suited to its employment it is one of the best pumps for irrigation. It is adapted to raising water heavily charged with sediment. In construction a centrifugal pump is similar to an outward-flow turbine driven in the reverse direction. Such a pump can not be put in action until it is filled with water, an operation which is effected through an opening in its outer casing when the pump is below water, or by means of a steam jet when the pump is above water. The efficiency of a centrifugal pump diminishes with the lift, and for lifts exceeding 25 to 30 feet a force or plunger pump produces better results. Centrifugal pumps are usually driven by water, steam, or gasoline motors, with which they are connected by belting or shaft and gearing, and they may be erected independently of the motors and at some distance from them (Pl. VIII). They are also made to gear directly on the motor shaft.

Many forms of centrifugal pumps are now in the market. They are of varying capacities, from those having 2-inch discharge pipes up to those having 24-inch discharge pipes, the largest sizes being capable of elevating as much as 15 second-feet, or the same number of acre-feet in a day of twelve hours. Such pumps as these vary in cost according to circumstances, but the larger sizes cost for plant about $100 per second-foot of capacity for moderate lifts, while for 15 second-foot pumps they require engines capable of developing about 5 horsepower per foot of lift.

Among the more notable centrifugal pumping plants for irrigation is one for the Vermilion Canal Company in Louisiana, consisting of six 15-inch pumps, which are claimed to be capable of discharging 130 second-feet of water against a head of 20 feet, and are operated by two engines, each of 250 horsepower. Another centrifugal pump, working on a farm in southern Arizona and operated by a 10-horsepower engine



CENTRIFUGAL PUMP DRIVEN BY THRESHING ENGINE.

l boiler, has a capacity of two-thirds of a second-foot. The opera-
ı of this plant calls for the consumption of about 1 cord of wood per
r of twenty-four hours, and it is capable of irrigating about 3 acres
a season. A similar pump in the same locality and operated by a
ıoline engine of 35 horsepower will handle about 11½ acre-feet in
ınty-four hours on a consumption of about 84 gallons of gasoline.
ıer centrifugal pumps of small capacities and capable of watering
ı 10 acres per day, and in the course of an irrigation season from 50
100 acres, are operated by one man at a cost of about $2.50 per acre
gated for maintenance and $15 per acre for first cost of plant.

t is proposed to erect an extensive centrifugal pumping plant for
ı Summit Lake Water Company in California, and the estimates of
ı engineers for a plant capable of irrigating 40,000 acres, including
tributing canals and other items, is $81,000, the cost of the pumping
nt alone being estimated at about 75 cents per acre, while the cost for
ıration of and interest on the pumping plant during an irrigating
ıson is estimated to be about $1 per acre, on the assumption that
ı depth of irrigation will be 1 foot and the lift 20 feet. These figures
considerably below those of most gravity systems.

Rotary pumps, while theoretically the most efficient, are practically
ıable of elevating but small quantities of water, and have been found
small value in elevating water for irrigation. They may be termed
olving-piston pumps in distinction from direct-action pumps, and
ve the advantage of not changing the direction of flow of water
ring its elevation by each stroke of the pump. They can be run at
h speed, and have no complicated leather valves or pistons to be
ıked or otherwise get out of order. They are probably most useful
lifting silt-laden water or heavy fluids. There are numerous forms
these pumps in the market. A large machine of this type, made by
ı National Pump Company, is stated to be capable of lifting about
cre-feet of water in twenty-four hours to a height of 20 feet on an
ıenditure of about 5 horsepower, and to a height of 100 feet on
expenditure of 25 horsepower. The first cost of this machine is
)0, or about $150 per second-foot. The efficiency of rotary pumps
ow, there being an excess in driving power required over effective
rk performed.

MECHANICAL AND SIPHON ELEVATORS.

There are several varieties of mechanical water elevators, nearly all
which act on the principle of an endless chain carrying buckets.
is endless chain revolves on two wheels, one at the upper end of the
and one beneath the surface of the supplying well or stream. As
ı chain revolves, the buckets dip into the water and become filled,
l as they reach the upper end of their revolution they spill their
ıtents into a trough which leads it to the irrigating ditches. Two of
ı more popular patented varieties of mechanical water elevators are

the link-belt box water elevator and the Seaman irrigating pump.

The link-belt box elevator consists of an elongated box which is set up in an inclined position over the water supply, at either end of which is a wheel of peculiar construction carrying on its periphery a metal link belt or chain, attached to which at short intervals are wooden projections of such dimensions as to fill the cross-section of the box. As the chain travels forward these projections are raised, carrying with them the water resting upon them until it reaches the upper end of the box, where it is discharged into the irrigating ditch. This machine may be operated by animal, steam, or water power, and the largest sizes are capable of lifting about 5 second-feet with an expenditure of 7 horsepower for a 10-foot lift. The highest practicable lift of these machines is 20 feet, and one of this capacity costs $50 per second-foot.

The Seaman irrigating pump is similar to the apparatus just described, excepting that instead of a series of wooden flights or projections lifting water in a closed box it consists of a number of large galvanized iron buckets carried by the chain working in the open, the buckets being closed on all sides, with the exception of an opening on the bottom containing a ball valve retained by a little wire basket. When the bucket is filled the ball is pressed down in the basket so as to close the opening, and as the bucket reaches the upper part of its revolution the ball drops in the basket, permitting the water to flow out freely. The largest of these contrivances are capable of lifting about 1½ second-feet on an expenditure of 5 horsepower, the first cost being about $250.

There is manufactured in France, by Lemichel et Cie, an apparatus called a siphon elevator, which is claimed to attain an efficiency of 90 per cent. It consists of a siphon erected at a fall or dam in a river, at a reservoir dam, or in any situation where the lower discharge arm can be carried below the suction pipe so as to give a difference of elevation for the creation of siphon action. At the highest point of the siphon are constructed air and valve chambers, the effect of which is to relieve the siphon at that point of part of the water passing through it, only a portion passing on down through the longer arm of the siphon to keep up siphon action. It is this contrivance which enables water to be elevated by the siphon to heights as great as nearly 30 feet at sea level, instead of being delivered, as by common siphons, below the point from which it is derived.

The siphon elevator (fig. 17) depends for its efficiency on the operation of the air chamber or receiver and the regulator, which are placed at the upper bend of the siphon pipe. At the bottom of the suction pipe is a check valve which allows the ingress of water but prevents its escape. At the bottom of the lower arm of the siphon is a stop-cock which, when open, permits the escape of water, so that when it moves a vacuum is created behind it, which is filled with water, as in simple siphons. In action the siphon elevator must first be filled with

water, and as this descends in the lower pipe and ascends in the upper or suction pipe it passes through the receiver (*a*), where it reaches an open check valve which intermittently cuts off its flow into the regulator (*b*). The water forces this valve (*c*) forward until shut, and, its exit being thus cut off, its momentum raises a puppet valve (*d*) in the receiver held down by a spiral spring. Through this valve the water escapes into a storage tank or irrigating ditch. While the regulator is being partially emptied into the pipe a vacuum is caused, which creates a depression in the corrugated heads of the regulator, as in an aneroid barometer, and the pressure on the clack valve (*c*) being diminished, it is thrown open by a weight on a lever, permitting the water to fill the regulator once more and the corrugated heads to again assume their normal position. This vibratory motion occupies but a brief time, as many as 150 to 400 such pulsations taking place per minute, so that the flow of water is nearly continuous.

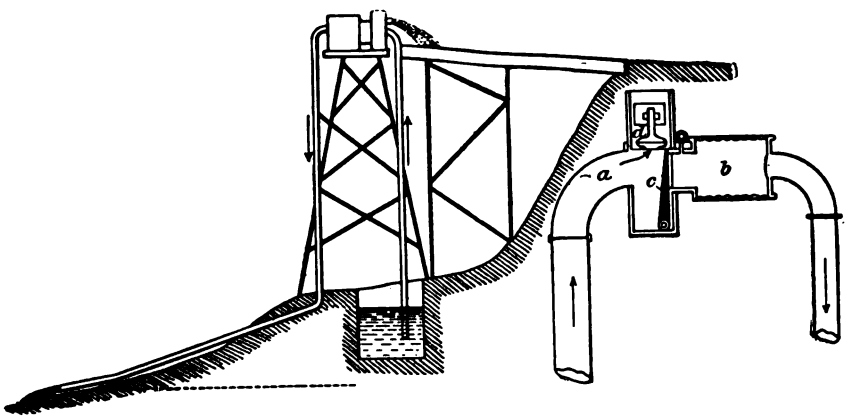


FIG. 17.—General view and detail of siphon elevator.

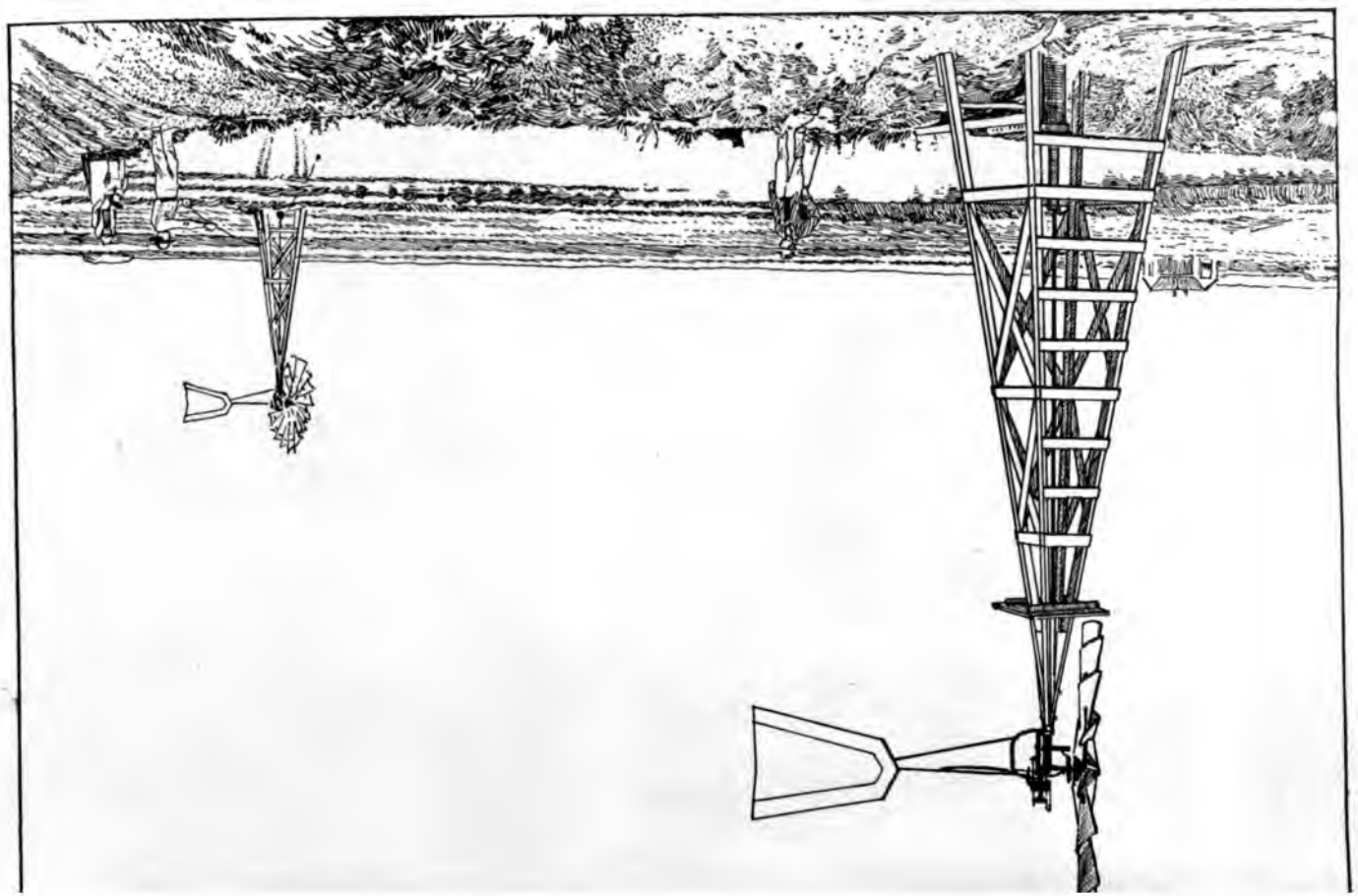
The capacity of these siphon elevators varies according to their dimensions and the height to which they elevate the water, but at sea level they have been built with capacities sufficiently great to elevate 8 acre-feet in twenty-four hours. This is a very large quantity when the simplicity of construction and cheapness of first cost of this mechanism—about $1,200—are considered; and it may be safely stated that if further experiment with it shows it to be as effective as claimed in the past, it will be a valuable water-lifting apparatus where only trifling heights—say 10 to 15 feet—are to be overcome and there is sufficient fall and surplus water to permit of the wastage caused by the operation of the siphon. Batteries of two or three of these siphon elevators have been erected, one above the other, whereby, with additional wastage of water for each siphon, heights two or three times those to be effected by one siphon elevator have been obtained.

STORAGE RESERVOIRS.

The storage reservoir or tank employed to retain water which has been pumped when not required for irrigation should be situated at the highest point on the irrigable land. When there is but little slope to the land it may be impracticable to build an earth reservoir at a sufficient elevation to obtain a good head, in which case a wooden or metal tank should be used. Such tanks can be gotten from any of the windmill makers, and range from 10 to 30 feet in diameter, their depths varying between 3 and 20 feet and their capacities from 1,000 gallons upward. These tanks (Pl. II, p. 30), when constructed of wood, are made of the best selected clear pine and are bound by from 3 to 20 iron hoops, depending on the dimensions of the tank. Their prices range from $30 to $800 each.

Where artificial reservoirs can be constructed on the land, it is best, provided suitable material for rendering them impervious can be found, to build them up by constructing about the reservoir an embankment rather than by making an excavation in the ground. The reason for this is that the former mode of construction places the water surface at some height above the ground level and, besides making a larger volume of the water supply available, gives a better head for flowing it through the ditches. The most economical way in which to construct such reservoirs is to find a gully or depression of some sort in one of the higher portions of the land and build across the lower end of this an earth embankment. This is rarely possible on the level plains, where it is necessary to wholly surround the basin by an artificial embankment.

For the latter type of reservoir the best shape is circular, as such is more easily built and has a larger capacity for the same amount of material moved (Pl. IV, p. 34). The ground should first be deeply plowed and stripped of the surface soil, and this loose material be used as a portion of the outer face of the inclosing embankment. The cross-section of the latter should be rather flat, its slopes depending upon the nature of the soil. Where a firm, clayey gravel can be obtained, free of vegetable mold and other foreign substances, this will make one of the most impervious embankments. It may be given a cross-section as steep as about 1½ horizontal to 1 vertical on the inside, and about 2 horizontal to 1 vertical on the outside, with a top width of not less than 4 feet. For less suitable material, as more sandy soil, or that containing some admixture of loam, flatter slopes must be used, reaching even as low as 3 horizontal to 1 vertical inside, and 3½ or 4 to 1 on the outside. In every case such an embankment should be built up in horizontal layers, well and deeply bonded with the subsurface soil, these layers not exceeding 6 inches in thickness and being separately tramped by animals or rolled by heavy rollers as laid. If there is available a gravel containing sand and a little clay matter, the embank-



ent may be built up dry, and will form one of the most impervious ructures that can be made. With less firm materials a puddle wall ould be built up through the center of the bank as it is erected. Such puddle wall should consist of gravelly clay, moistened as it is laid, id at least 2 feet in thickness for low embankments, its base being mly and deeply bonded with the subsoil. The top of the embankment ould reach at least 2 feet above high-water surface (Pl. IX), in order prevent its being overtopped by waves during high winds, and the ter slopes should be sodded to protect them against erosion by heavy infalls. The reservoir should not be too large for the pump to easily l, in which case the percentage of loss from evaporation and absorption would be too great. It should be as deep as practicable, for the eper the less its area and the less the surface exposed to evaporation id absorption. A reservoir 100 feet in diameter and 5 feet deep will se nearly all its water in a few months, whereas one 50 feet in diameter id 10 feet deep will lose scarcely 25 per cent by absorption and aporation in the same time.

If homogeneous clayey soil underlies the bottom of the reservoir it ill be unnecessary to provide a lining, though there may be some loss water through percolation and absorption. If such a surface is not vailable for the bottom, the soil should be removed and the subsoil overed with a layer at least 1 to 2 feet in thickness of clay and gravel, he same being carefully puddled and rolled over the entire surface and p the inner slope of the embankment so as to make a firm bond with . Better still, if means permit, is it to line the inner surface of the eservoir bottom and slopes with asphaltum. This is put upon the enuded subsoil much as is the asphaltum used in paving city streets. ne of the best admixtures is about 75 per cent of La Petra asphalt, he remainder being of Las Conchas as a flux, both of which come from ower California. This is boiled in open kettles for twelve hours at high temperature, frequently stirred, and 20 per cent of it by weight mixed with 80 per cent of sand previously heated to the same mperature. This should be put on with a thickness, for shallow reservoirs, of 2½ inches, spread with hot rakes, tamped with hot tampers, nd held in place on the slopes by anchor spikes of sheet iron about an ch wide and driven in at intervals of about a foot. This lining should e painted over with a bitumen paint or Trinidad asphaltum fluxed with siduum oil and poured on hot from buckets. Such a lining laid over well-leveled and well-rolled surface will last many years, will be impervious to water, and as it will cost but 15 to 20 cents per square foot, will obably more than pay for itself in a short time in the saving of water.

To control the flow of water from the storage reservoir a discharge outlet gate should be firmly built into the banks in such manner at seepage water will not find its way along it and thus erode the servoir wall. It should be located at the lowest point of the reservoir bed, which may be previously graded to slope toward it. Such

an outlet sluice may be satisfactorily constructed of wood by building out wing walls on both the outer and the inner surfaces of the embankments and inclining its bottom ends downward into the ground so as to prevent the seepage of water about the resulting box-like channel or flume. Additional security against the travel of seepage water may be had by running a row of sheet piling tightly connected with the box flume back through the center of the embankment for some distance. In this box flume should be erected a small lifting gate which can be raised to any desired extent so as to permit of the discharge of such volumes as may be required in irrigating the fields.

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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 2

IRRIGATION NEAR PHOENIX, ARIZONA.—DAVIS.

WASHINGTON
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The following list contains the titles and brief descriptions of the principal w
relating to water supply and irrigation prepared by the United States Geol
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1890.

First Annual Report of the United States Irrigation Survey, 1890, octavo, 123

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geo
Survey, 1888-89. Contains a statement of the scope of the Irrigation Survey, a prelim
report on the organization and prosecution of the survey of the arid lands for purposes
gation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, 32

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States G
ical Survey, 1889-90. Contains a description of the hydrography of the arid region and
engineering operations carried on by the Irrigation Survey during 1890, also the status
the Director of the Survey to the House Committee on Irrigation, and other papers, inclu
bibliography of irrigation literature. Illustrated by 30 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891, octavo, 376

Printed as Part II of the Twelfth Annual Report of the United States Geological S
1890-91. Contains a report upon the location and survey of reservoir sites during the
year ending June 30, 1891, by A. H. Thompson; "Hydrography of the arid regions," by
Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 109 i

Bulletins of the Eleventh Census of the United States upon irrigation, prep
by F. H. Newell, quarto.

No. 55, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Ir
tion in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Mon
No. 157, Irrigation in Idaho; No. 159, Irrigation in Nevada; No. 178, Irrig
in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in W
ington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin N
September 9, 1892, quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holding
total area and average size of irrigated farms in the subhumid regions, the percentage o
ter of farms irrigated, characteristic crops, value of irrigated lands, the average cost of irrig
the investment and profits, together with a sketch of the water supply and a description
gation by artesian wells. Illustrated by colored maps showing the location and relative
of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Par
Irrigation, 1892, octavo, 400 pp.

Consists of three papers: Water supply for irrigation, by F. H. Newell; American engin
and engineering results of the Irrigation Survey, by Herbert M. Wilson; Construction a
graphic cases and selection and survey of reservoir sites, by A. H. Thompson. Illustra
17 plates and 110 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell,
octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geol
Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent
different basin of Yakima River and the great plains of the Columbia in the east of this
with special reference to the occurrence of artesian waters.

(Continued on third page of cover.)

DEPARTMENT OF THE INTERIOR

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OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 2

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1897

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

IRRIGATION NEAR PHŒNIX, ARIZONA

BY

ARTHUR POWELL DAVIS

WASHINGTON

GOVERNMENT PRINTING OFFICE

1897

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, January 25, 1897.

SIR: I have the honor to transmit herewith a paper entitled "Irrigation near Phœnix, Arizona," by Arthur P. Davis, hydrographer, and to recommend that it be published in the series of papers "in relation to the gauging of streams and to the methods of utilizing the water resources," the printing of which was authorized in the act making appropriations for sundry civil expenses of the Government for the fiscal year ending June 30, 1897, approved June 11, 1896.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

PREFACE.

The storage of flood waters on a large scale is fast coming to be a tter of prime importance in connection with the development of arid portions of the United States. The irrigation projects which olve comparatively small expenditure, or which can readily be ıdled by associated effort, have already been entered upon, but re still remain many localities where, as time goes on, the neces- for water conservation becomes more and more pressing. This especially the case in southern Arizona, in the Salt and Gila valleys. re, under the genial semitropic conditions, large returns are ob- ned from the fertile soil, some of the most valuable fruits are raised, l crop follows crop in rapid succession, farming operations being ıtinued throughout the year.

The success of agriculture has been such that a considerable num- of large irrigating canals have been built and lateral ditches ended until the available supply during low water has been practi- ly exhausted. The streams of this country are, however, extremely egular in character, fluctuating at times with great rapidity, floods ning down without warning, and disappearing in the course of a hours. At certain seasons of the year high waters prevail and ı to waste to the Gulf, or disappear by evaporation and percolation o the sandy desert. It is obvious that by providing suitable stor- works the area of land to be irrigated can be greatly increased, limiting conditions being practically the cost of storing water ative to the value of the crops produced.

The conditions briefly described above are not peculiar to the vicin- of Phœnix, or even to the Territory of Arizona; they prevail in ater or less degree throughout the more arid parts of the United ıtes, for in nearly every portion of this country irrigation has been nonstrated to be successful and largely profitable. Systems of ter supply have been built, the more easily available waters utilized, l the extension of irrigable lands now rests mainly upon the con- vation of waste waters. It is for this reason that a discussion of conditions near Phœnix, Arizona, has an interest not only to the zens of that locality, but in general is of value to residents in other tions of the West. In certain respects the needs for water are more

pressing in southern Arizona than elsewhere, and thus the probabilities of early solution of some of the problems of water storage are here more likely to be settled in the near future. For this reason the following paper by Mr. Davis will be of benefit to a larger circle of readers than those to whom, from the title, it may appear to be addressed.

In order to make clear all of the surroundings, Mr. Davis gives a general description of the topographic and climatic conditions of the Salt and Gila valleys, and of the irrigation works already constructed. He also mentions the legal complications which have arisen, and outlines some of the projects now being constructed. He points out the great natural advantages of this country, and shows as far as data can be procured the facts relating to water supply, evaporation, silting of reservoirs, and other factors which make or mar projects of water conservation.

At first sight the storage of water appears to be a very simple matter. In popular discussions it is common to assume that the only steps necessary are to place rock or timber obstructions in some of the many canyons or narrow places along the course of the river in order to hold back the water of floods, and later allow it to flow down the stream as necessity requires. On carefully examining any proposition of this kind, many obstacles are found to arise, some of these natural—such as the difficulty of finding a proper location, the expense of laying foundation, and the liability of the reservoir to fill by silt—and others artificial or legal, such as interference with vested rights, and difficulties of securing title to the stored water after it has left the reservoir and is on the way to the land to be covered.

A traveler going over the Territory sees here and there almost numberless places where it appears probable that a storage dam might be built holding behind it considerable water, but when a careful survey has been made it is usually found that the slope of the stream is so great that if a dam were built the amount of water held behind it would be relatively too small to repay the cost of construction. Should it be found that there is ample space behind the selected dam site, further investigation may reveal the fact that solid rock can not be found at moderate depth beneath the surface. In other words, the stream has washed into the gorge such a mass of loose material as to fill it to a depth of 20, 40, or even 60 feet or more. To remove this, place the foundation on bed rock, and then rear a structure to the proper height, will necessitate the expenditure of such large sums as to render the enterprise impracticable. This is a very common condition within the arid region, where the drainage lines, dry for a great part of the year, are filled, perhaps for a few days or even a few hours only, with a great torrent resulting from excessive local rainfall. The water discharged down the steep slopes dislodges not only the accumulated sand and dust which has been blown about by the desert winds, but rolls along gravel and bowlders into the channels. Even

in the narrow gorges through which these sometimes pour the velocity of the water is not sufficient, except perhaps in extraordinary floods, to tear out the loose material and reach bed rock. Thus the gravel and bowlders accumulate during the lesser floods all along the course of the stream, covering the dam sites, and form long lines of barren wash.

Not only does the loose material transported by the floods cover the bottom of many otherwise feasible dam sites, but deposits of this character constantly imperil and shorten the life of all storage reservoirs. The flood waters bear this along, and when brought to rest drop the heavier material at first and then the lighter, retaining only the finest particles, the greater part of which in time may settle within the interstices of the coarser. Thus the upper ends of all reservoirs are rapidly filled with silt, and it becomes an important question to the projectors of storage works as to how many years will elapse before the value of the reservoir is practically destroyed and whether its use can be restored in part by subsequent removal of some of this material.

The legal obstacles are in many localities no less vexatious than those offered by nature. While many principles have been settled in regard to the use of water for irrigation, their application to particular cases is still a matter of doubt. Even in the case of persons diverting water from perennial streams there are innumerable controversies whenever a shortage occurs. But when a portion or all of the surplus water is being held in reservoirs and returned perhaps to the same stream, to be again recovered, there can not fail to be still greater complications than those now brought to the attention of the courts. The primary cause of most of the contentions which arise is the lack of exact knowledge concerning the amounts of water which are flowing in the streams from day to day and the quantities taken out by different canals. These are not only fluctuating, but the matter is complicated by the disappearance of water by evaporation and the reappearance of other waters in the natural drainage lines by seepage from canals above, or from the slow progress of water coming originally from rainfall and finding its way gradually toward the lowest points.

When one has noted the interminable lawsuits over water rights and appreciated the fact that most of these are due to lack of precise knowledge as to past conditions, it appears almost incredible that greater care is not being taken to ascertain exactly how much water is flowing at different points in the natural streams, especially in view of the fact that later large investments are to be made in storage projects. It is, however, a lamentable fact that very little attention is given to this matter, mainly perhaps because the persons investing in irrigation works are usually from humid climates, and it never occurs to them that rivers do not always have water to spare within their

channels. Yet in southern Arizona, where, as in other portions of the arid regions, the rivers at certain seasons of the year diminish and even cease flowing, enormous investments are being made upon crude assumptions as to the quantity of water available, these assumptions being supported only by a few isolated facts or measurements.

The determining point in the construction of storage works, after their feasibility has been settled upon, is whether they will pay—whether the value of the water thus obtained and the benefits derived are sufficient to make the projects remunerative. The answer to this question depends largely upon what may be considered as profitable; for example, if these storage reservoirs are under consideration by corporate enterprise, it will be necessary to show that the annual water sales or rentals will not only repay the expense of management and a fair interest on investment, say 6 or 8 per cent, but will also yield a surplus which can be used as a sinking fund to repair damages or ultimately cover the cost of the works, should these be gradually deteriorated by accumulation of silt. The aggregate of these items is large and may amount to 10 per cent or upward. Thus it is necessary to show that the storage works will, after completion, pay for themselves within a brief period; otherwise individual capital will not be attracted.

If, on the other hand, these reservoirs, or the best of them, are built by the whole community interested or by State or national funds, the question of immediate profit does not enter so largely into the calculations. In this latter case the indirect benefits to be derived by the people offset to a certain extent the interest charge, and if the works can be shown to pay the cost of maintenance and provide a small sinking fund, they may be considered as feasible. Thus it is that a project which will be condemned by the investor as worthless may at the same time be of the utmost value to the community and one which would well repay cost of construction if this cost were distributed uniformly to all benefited.

The situation in the Salt and Gila river valleys is fairly typical of that elsewhere as regards the probable profits to be obtained by constructing storage reservoirs. Briefly stated, it may be said that the canal systems already constructed or partially completed cover a larger area of land than can be supplied by the average summer flow of the streams. Water from reservoirs is needed for lands already under ditch and whose owners have already purchased water rights. There are above these ditches still larger tracts of land which would be valuable if water could be had, but it is apparent that the greatest good would result from securing an ample supply of water to the lands already partly cultivated rather than indefinitely increasing the area of poorly watered farms.

If a corporation contemplates building a reservoir within the Gila Basin, the first question is, Shall the attempt be made to sell the water

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the cost of construction, rather than attempt to supply water to land already under ditch and partly irrigated.

Some of the best storage projects, however, are so situated that th water can not be taken readily to new areas, and it appears prol able that these, although among the most important in the country can only be constructed by the adoption of some scheme by which al of the lands of the valley benefited directly or indirectly will be force to contribute an amount equal to the benefits derived. This is possi ble only under some system similar to that of the district organizatio in California, where all of the lands receiving water from a give source are assessed. Here it is not necessary to consider whether th enterprise will be money making in itself. Thus it is possible to pus forward the construction of beneficial works which otherwise neve could be built.

F. H. N.

THREE-YEAR OLD ALMOND GROVE NEAR PHOENIX, ARIZONA.

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drainage lines and almost destitute of water. Sharply contrasted with these facts are the conditions on the southern slope. Here, through most of its course, the plateau drops off with a very steep slope, which is deeply cut with drainage lines in which are living creeks and rivulets of clear, beautiful water, such as San Francisco River, Black Creek, Bonito Creek, White River, Carrizo Creek, Cibicu Creek, Box Creek, Cherry Creek, Tonto Creek, Wild Rye Creek, East Verde River, Pine Creek, Fossil Creek, Clear Creek, Beaver Creek, etc.

The region of high altitude, as before remarked, lies largely north of the divide, while the great bulk of the water flowing from the plateau, as proved both by erosion of drainage lines and by the volume of permanent streams, flows away to the south. The explanation of this is partly the porosity of the strata composing the plateau, which allows the water to sink instead of flowing off the surface. Once underground, its egress to the south is favored by the shorter distance which it must percolate on a given grade before reaching a surface, due to the more abrupt slope.

Another partial explanation is found in the meteorological condition. The moisture of this region is brought from the Pacific Ocean and the Gulf of California by the prevailing southwest wind. As this wind ascends the elevations toward the Colorado Plateau, its temperature is lowered, which reduces its capacity for holding moisture and increases its relative humidity. When this quantity reaches 100 per cent in any part, precipitation occurs. This influence continues until the wind passes the summit, where the process is reversed.

As might be expected, therefore, the hydrographic resources of the country immediately southwest of the Colorado Plateau are disproportionately great when compared with those to the northward. For instance, the precipitation at Fort Apache, as shown by a mean of twenty years' observations, is 19.75 inches, the elevation being 5,050 feet, while the precipitation at Holbrook, at an elevation of 5,047 feet, on the northern slope, is 8.47 inches, as indicated by the mean of ten years' observations. This is an important fact, especially when taken in connection with the fact that the great areas of valley land with a semitropic climate lie in the southwestern portion of the Territory, and are easily covered by the streams which are formed by the conditions above described, and which constitute the main features of the great Gila river system.

GILA BASIN.

The drainage area of Gila River, including a number of small lost basins which are topographically tributary but which seldom or never furnish any run-off to the main stream, is about 72,000 square miles, of which nearly 57,000 lie in the Territory of Arizona, about 14,000 in New Mexico, and something over 1,000 in Mexico. The areas in

the United States are distributed, with respect to elevation, approximately as follows:

Distribution of area of Gila Basin by altitude.

Elevation.	Per cent of area of basin.	Area, square miles.
Under 1,000 feet	9	6,400
Between 1,000 and 2,000 feet	19	13,500
Between 2,000 and 3,000 feet	16	11,400
Between 3,000 and 4,000 feet	14	10,000
Between 4,000 and 5,000 feet	15	10,700
Between 5,000 and 6,000 feet	12	8,500
Between 6,000 and 7,000 feet	8	5,600
Over 7,000 feet	7	4,900
Total	100	71,000

Gila Basin is conveniently divided into four parts. Of these, the most northerly is Salt River Basin, which includes all the territory tributary to Salt River. This again is sharply divided into its valley and mountain portions. Salt River Valley (see map, Pl. XXX) may be taken as including all the territory adjacent to Salt River from its mouth up to the junction of the Rio Verde. Above that point the greater portion of the basin is mountainous, with small valleys on the Rio Verde, in Tonto Basin, and at a few points on Salt River and other tributaries. The Lower Gila district may be taken as the portion lying below the mouth of Salt River; the Middle Gila district, that portion from the mouth of Salt River to The Buttes above Florence and including the Pima Indian Reservation and the great Casa Grande Valley. The Upper Gila district includes the valley in the region of Camp Thomas and Solomonsville and the tributary mountainous districts. In addition to these main divisions of the trunk streams may be taken the subordinate divisions of tributaries, such as San Pedro, Santa Cruz, Hassayampa, and Agua Fria creeks.

TEMPERATURE.

The tables of temperature for the Gila and Salt River valleys show that the climate is very warm. But care should be taken not to exaggerate this feature, for the actual conditions in their relation to human life and comfort are by no means as unfavorable as they might appear to persons comparing these tables of temperature with those of some Eastern localities. For about eight months in the year the temperature of this valley is delightful. Cool nights, bracing mornings, and

bright, pleasant days are the rule, except in the months of June, July, August, and September. In these months the heat becomes intense, and though there is of course some variation, the temperature remains continually high throughout the greater part of this period.

The physiological effect of this heat is markedly modified by the aridity of the climate. The human economy provides that when the temperature of the healthy body rises above the normal the perspiratory glands begin to act and furnish the skin with moisture, the evaporation of which lowers the temperature of the body. An essential condition of this natural safeguard against excessive heat depends upon the ready evaporation of the moisture furnished by nature. In a very humid climate this evaporation can not occur; and in those portions of the country where the humidity is comparatively high such evaporation must be proportionately tardy and sluggish, so that any considerable temperature above normal blood heat produces great suffering and exhaustion, and even prostration. In an arid region, on the contrary, the low percentage of humidity causes prompt and quick evaporation of the moisture and the consequent success of nature in its attempt to prevent uncomfortable and injurious bodily temperature. In southern Arizona these favorable conditions for resistance to heat are at their maximum. Though the temperature is high, the relative humidity is very low, and every particle of moisture which reaches the surface of the skin is promptly evaporated—so promptly that its presence is not perceived—and while the body is thus kept at its normal temperature the unpleasant effects of excessive moisture are not experienced, and the sultry, sticky days so common in the East are unknown in Arizona.

The principles involved in these facts are frequently illustrated to the sojourner in southern Arizona in the following manner: Riding in a wagon or buggy in the month of July the traveler may feel greatly oppressed and enervated by the intense heat; the climate seems well-nigh insupportable; but if he will get out and walk for a short time, the circulation induced by the exercise starts the perspiration and the traveler is surprised to find himself greatly refreshed, and he may then resume his ride in comfort. Farm labor, the construction of canals, the rounding up and branding of cattle, and other active, hard labor are performed at any time in the summer with less comfort, of course, but with no worse effects, than at any other time of year, and without actual suffering, the only requisite being plenty of drinking water.

A fair comparison of the sensible temperatures of two places may be obtained by a comparison of the readings of wet-bulb thermometers. The difference between the readings of wet and dry bulb thermometers here often exceeds 30 degrees. The summer is, therefore, far from being as uncomfortable as might be supposed, and the delightful autumn, winter, and spring fully compensate for the discomforts

of the summer months; and the climate, taken as a whole, with its extreme aridity, its mildness, and its large proportion of sunshine, is exceptionally healthy and especially beneficial to those suffering from bronchial or pulmonary troubles.

RAINFALL.

Rainfall records of Arizona, from the date when they began up to and including the summer of 1890, were prepared by Capt. William A. Glassford and published in a Report on the Climatology of the United States, with Reference to Irrigation, by Gen. A. W. Greely, Chief Signal Officer.[1] Later records may be found in the various annual and monthly publications of the Weather Bureau, and it is deemed of value to reproduce some of them here, brought up to date, partly because of the scattered condition of the original records, some of them being now out of print, and partly for the reason that for purposes of irrigation the season is best divided about the end of August. Rainfall occurring after September 1 can not in most cases be relied upon for irrigation use in that season, but may be stored for use in the following year. Precipitation occurring before this date may usually be utilized the same year, especially if storage is provided.

No arbitrary line can be drawn separating the precipitation available in one year from that available only by storage for the next, but it is thought that more cases will occur where September precipitation can be used the same year than where August precipitation can not, and that it is fair to divide the season as above indicated. For the convenience of those contemplating storage works, therefore, the tables are rearranged and the total annual rainfalls recomputed on this basis. A glance at the annual and monthly means shows at once that agriculture in the valleys of southern Arizona must depend entirely upon irrigation.

Short fragmentary records in Arizona are of very little value, on account of the erratic nature of Arizona rainfall, which is peculiarly marked during the summer rainy season. This season is characterized by sudden violent local thundershowers, often called cloudbursts, and while in a long series of years such local storms probably distribute themselves with a fair degree of uniformity over districts governed by the same general conditions, yet a short record may be so affected by them as to be abnormal. A station receiving one or more storms of this character, or being avoided altogether, as is likely to occur in a short record, may give results that will be very misleading. For instance, at Fort Lowell, which is but 9 miles east of Tucson, and only 4 feet lower, there fell during July and August, 1878, 0.60 and 7.88 inches of rain, respectively, while at Tucson during the same months the rainfall was 5.72 and 4.71 inches. Such discrepancies would probably disappear

[1] Fifty-first Congress, 2d session, H. R. Ex. Doc. No. 287, Irrigation and Water Storage in the Arid Regions.

in the average of a long series of observations. Very short records, on account of the great secular variations even in countries of greatest uniformity, can not be depended upon as giving the average rainfall for the region in which they are taken. In this climate, for the reasons given above, they are of little, if any, value, even when a long record exists in such situation that a comparison of its mean with that of the short record may be made.

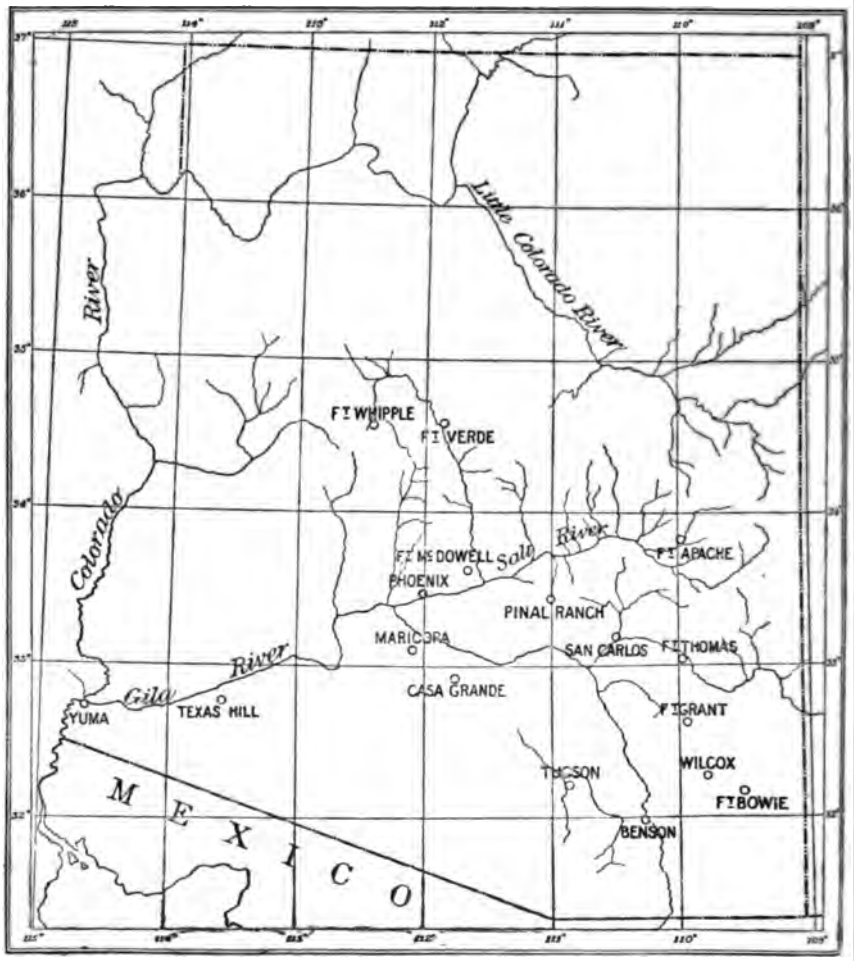


FIG. 1.—Map of Arizona, showing location of rainfall stations.

In a region like Arizona, where the water supply bears such a vital relation to its prosperity, and where, moreover, the means available for keeping rainfall records are limited, rainfall stations should be, and usually are, so far as practicable, widely distributed over the Territory, in order that all varieties of elevation, topography, latitude, and climatic conditions may be represented. Such records, if care-

fully kept for a long series of years, say twenty or more, become valuable for determining the actual rainfall to be expected in any particular locality by means of a short record embracing four or five years. The comparison of such short record with the synchronous record at the station of long observation establishes an approximate relation between the point under investigation and the point at which the long record was taken. In a similar manner a comparison may be made between the measured discharge of any given stream and the synchronous rainfall at the old station, and in a few years a relation can be thus established from which may be derived an approximate hypothetical history of the stream or hydrographic basin under investigation.

The value of these old records, which, unfortunately, are very rare, depends chiefly upon their continuation. It may be broadly stated that the older such a record becomes the stronger is the argument for continuing it. It is especially to be deplored, therefore, that some of the old records in Arizona have been discontinued. For instance, Fort McDowell, having in 1891 the oldest continuous record in Arizona, was in that year discontinued, and has not since been resumed. A great part of the value of this old record might be restored if it were practicable to reestablish the station.

A selection has been made of 16 stations, most of them having a record covering at least fifteen years, so distributed as fairly to indicate the means and extremes of precipitation in the various portions of the basin. A short record at Pinal ranch, not hitherto published, is also included. These records are contained in the following tables:

Record of precipitation at Fort Whipple, Yavapai County.

[Latitude 34° 33′, longitude 112° 28′; elevation, 5,389 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1866-67...	3.65	0.57	0.08	0.31	1.72	1.16	8.00	0.06	1.17	0.00	2.70	2.38	21.80
1867-68...	.....	0.10	0.20	2.20	2.97	5.30	0.50	1.00	.....	0.00	6.16	2.72	.....
1868-69...	0.30	0.55	1.50	4.40	0.80	0.92	.....	.....	.....	.....	.....	.....	.....
1869-70...	[1.08]	1.40	1.45	0.00	0.00	1.20	1.09	0.26	1.73	0.24	7.98	3.49	19.92
1870-71...	0.00	1.59	0.30	0.53	0.70	1.01	0.10	1.92	0.47	0.00	4.00	1.80	12.42
1871-72...	1.51	1.40	0.52	0.00	0 50	0.80	0.12	1.62	1.47	1.24	3.74	6.25	19.17
1872-73...	0.04	0.24	0.00	0.64	0.00	1.00	0.23	0.17	0.40	0.42	1.56	4.78	9.48
1873-74...	0.30	0.00	0.80	2.55	5.51	5.68	3.56	1.70	0.65	0.00	5.72	1.56	28.03
1874-75...	0.00	0.50	.....	.....	.....	.....	.....	.....	0.00	0.00	5.92	1.66	.....
1875-76...	0.77	0.00	0.18	0.63	4.60	0.01	0.83	0.51	0.52	0.25	3.28	4.51	16.09
1876-77...	0.72	0.93	0.00	0.00	0.36	0.56	0.49	1.50	1.82	0.00	1.29	0.24	7.91
1877-78...	2.42	1.36	0.00	2.23	0.28	2.02	0.48	2.86	0.33	0.33	0.91	6.34	19.56
1878-79...	0.61	0.00	0.45	1.02	0.91	0.94	0.05	0.03	0.00	0.05	1.87	2.20	8.13
1879-80...	0.68	0.37	1.58	4.21	0.35	0.16	0.11	0.52	0.00	0.04	2.34	2.80	13.16
1880-81...	1.26	0.18	0.42	1.84	0.16	0.10	2.91	0.67	0.42	T.	3.27	5.25	16.48
1881-82...	1.69	0.33	0.30	0.33	2.53	2.04	0.00	0.28	0.45	0.47	1.64	3.34	13.40
1882-83...	2.57	0.39	1.55	0.00	0.31	0.63	2.33	0.86	0.15	0.09	3.20	3.26	15.34
1883-84...	0.33	0.43	T.	4.54	0.25	6.55	5.51	1.62	1.45	0.32	1.33	1.57	23.90

Record of precipitation at Fort Whipple, Yavapai County—Continued.

[Latitude 34° 33′, longitude 112° 28′; elevation, 5,389 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1884–85...	0.99	1.42	0.16	5.58	0.08	0.46	1.47	0.62	0.37	0.07	2.53	1.24	14.99
1885–86...	0.11	0.38	2.46	0.32	5.99	1.15	3.04	1.18	0.03	0.00	0.61	4.41	19.68
1886–87...	0.46	0.23	1.68	T.	T.	3.12	T.	2.57	0.43	0.57	2.64	0.71	12.41
1887–88...	4.88	0.05	1.57	0.82	1.30	1.68	1.66	0.52	1.96	0.00	2.49	1.42	18.35
1888–89...	0.62	1.75	3.18	2.94	1.73	1.35	2.91	0.19	T.	0.02	1.45	1.51	17.65
1889–90...	2.11	1.76	0.42	7.38	2.29	3.02	1.52	0.86	0.00	0.06	2.19	2.67	24.28
1890–91...	1.48	.....	.....	.....	0.00	5.96	0.86	T.	0.27	0.00	1.86	3.04	.....
1891–92...	1.48	0.00	0.00	1.19	1.98	1.64	1.91	0.58	0.85	0.00	1.74	2.04	13.41
1892–93...	0.14	1.41	0.00	0.61	1.18	0.47	3.26	0.00	0.88	0.00	1.31	4.30	13.56
1893–94...	0.57	0.15	1.16	0.73	0.30	0.30	0.88	0.00	0.23	T.	1.13	3.88	9.33
1894–95...	0.45	1.37	0.00	3.43	4.37	0.55	T.	0.25	0.50	0.00	0.88	3.53	15.33
1895–96...	0.09	0.24	3.59	0.50	0.55	0.20	0.81	0.35	T.	0.14	4.70	2.61	13.78
Mean..	1.08	0.66	0.84	1.75	1.44	1.10	1.59	0.81	0.59	0.15	2.77	2.95	16.66

Record of precipitation at Fort Verde, Yavapai County.

[Latitude 34° 32′, longitude 111° 47′; elevation, 3,160 feet. Authority, Signal Service and United States Hospital Service.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1868–69...	.....	.....	.....	0.27	0.34	1.72	1.00	0.09	0.03	0.83	0.07	7.26	.....
1869–70...	0.00	0.02	4.04	0.00	0.50	0.01	0.50	0.15	0.00	0.22	3.06	0.89	9.39
1870–71...	0.00	0.60	0.10	0.58	0.20	0.00	0.04	0.73	0.00	0.00	0.84	0.26	3.35
1871–72...	1.00	1.10	0.39	0.26	0.47	1.12	0.16	1.56	0.54	0.22	2.22	4.35	13.39
1872–73...	1.12	0.10	0.00	0.83	0.00	1.16	0.00	0.00	0.15	0.20	0.14	2.52	6.22
1873–74...	0.26	0.00	0.74	3.26	2.65	2.05	1.05	1.48	0.08	0.00	1.88	2.48	15.93
1874–75...	0.00	1.45	3.52	0.06	2.91	0.05	0.30	T.	0.06	0.00	3.33	2.01	14.29
1875–76...	1.35	0.00	0.65	0.13	2.06	0.75	1.00	0.75	0.00	0.98	5.31	12.08	25.06
1876–77...	2.40	2.10	0.15	0.00	0.71	0.51	0.89	0.85	1.70	0.00	0.70	0.41	10.42
1877–78...	2.08	0.45	0.05	2.23	0.14	1.12	1.84	1.75	0.16	0.06	2.10	4.60	16.56
1878–79...	0.98	0.00	0.36	1.24	0.20	0.14	0.00	0.10	0.00	0.00	0.97	0.53	4.52
1879–80...	1.40	0.23	2.40	3.03	1.08	0.13	0.30	0.27	0.00	0.16	1.85	0.97	11.82
1880–81...	0.19	0.57	0.13	1.56	0.07	0.12	2.64	0.97	0.07	T.	1.41	7.53	15.26
1881–82...	1.88	0.20	0.21	0.27	2.72	0.93	0.01	0.03	0.19	1.35	1.25	1.18	10.22
1882–83...	2.16	0.25	1.73	0.07	0.44	1.35	1.03	0.12	0.27	0.04	3.35	1.14	12.55
1883–84...	0.00	0.45	0.00	4.30	0.39	3.59	3.60	1.43	0.72	0.23	0.19	1.24	16.14
1884–85...	0.68	0.84	0.15	4.66	0.00	0.80	2.25	0.69	0.19	0.05	0.84	3.01	14.16
1885–86...	0.03	0.61	1.88	0.52	1.90	1.48	2.09	0.82	0.02	0.01	0.18	3.18	12.72
1886–87...	0.20	0.13	0.55	0.60	0.04	0.78	0.02	0.58	0.60	0.18	3.11	2.96	9.75
1887–88...	4.72	0.00	1.37	0.87	0.96	1.56	1.78	0.43	0.96	0.00	2.21	0.73	15.59
1888–89...	0.56	4.47	2.80	3.15	1.95	0.25	1.66	0.00	0.00	0.02	3.10	0.75	18.71
1889–90...	1.60	1.74	0.08	5.08	1.39	1.97	1.35	0.82	0.01	0.00	1.83	2.30	18.17
1890–91...	0.55	[1.50]	[3.65]	[1.72]	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mean..	1.05	0.76	1.13	1.53	0.98	0.96	1.10	0.62	0.26	0.21	1.82	2.84	13.24

Record of precipitation at Fort McDowell, Maricopa County.

[Latitude 33° 38′, longitude 111° 38′; elevation, 1,250 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1866-67...	1.63	0.25	0.06	0.10	0.88	0.16	2.11	0.03	0.00	0.00	2.97	1.18	9.37
1867-68...	1.62	0.03	0.29	5.70	2.70	1.60	0.70	[1.00]	0.00	0.00	4.50	1.70	19.84
1868-69...	3.01	T.	0.01	0.00	0.64	2.60	0.00	0.15	T.	0.10	0.40	1.10	8.01
1869-70...	0.00	0.00	2.15	0.55	T.	0.60	0.65	T.	T.	0.70	0.90	1.98	7.53
1870-71...	0.22	0.40	0.00	T.	0.25	0.40	0.00	0.40	T.	T.	0.16	2.08	3.91
1871-72...	0.20	0.00	1.25	0.20	0.50	0.40	0.00	0.53	0.30	0.31	9.16	7.17	20.02
1872-73...	0.08	T.	0.00	1.56	0.00	1.60	0.90	0.00	0.16	T.	T.	0.56	4.86
1873-74...	0.00	T.	0.21	4.70	3.10	2.86	1.06	1.30	0.30	0.00	1.31	1.99	16.83
1874-75...	0.05	1.11	2.76	1.00	1.40	0.62	T.	0.10	T.	0.00	0.75	0.46	8.25
1875-76...	1.00	0.00	0.00	0.64	0.70	0.10	0.40	T.	0.00	1.00	3.25	1.70	8.79
1876-77...	0.00	T.	0.58	0.00	1.08	2.24	0.44	0.50	1.04	0.00	T.	0.06	5.94
1877-78...	1.52	0.38	T.	2.12	0.04	1.54	1.18	3.20	T.	T.	0.86	1.57	12.41
1878-79...	0.98	0.00	0.99	1.56	0.50	1.22	0.60	0.20	0.00	0.00	T.	0.12	6.17
1879-80...	0.34	0.58	2.14	2.64	1.56	0.38	0.50	0.38	0.00	T.	0.52	0.84	9.88
1880-81...	0.34	[0.40]	0.00	1.69	T.	T.	1.46	0.22	0.12	0.00	1.16	3.38	8.77
1881-82...	0.10	T.	0.80	T.	3.22	0.58	0.00	T.	0.10	0.56	0.40	1.52	7.28
1882-83...	1.34	0.00	1.38	0.00	0.59	0.78	0.42	0.00	0.28	0.04	1.12	1.76	7.71
1883-84...	0.32	0.30	0.06	4.22	0.33	4.37	3.47	0.58	0.45	0.09	0.08	1.25	15.52
1884-85...	3.96	1.38	0.45	4.54	0.00	2.50	0.60	0.00	0.00	0.00	0.00	0.90	14.33
1885-86...	0.90	0.40	1.75	1.25	3.35	1.60	1.50	T.	0.60	[0.00]	0.00	0.62	11.37
1886-87...	T.	0.27	0.44	0.30	0.00	0.86	0.00	0.68	T.	0.00	0.06	1.54	4.15
1887-88...	4.11	0.48	1.82	0.77	0.87	0.72	0.62	0.14	0.40	0.00	0.86	0.17	10.96
1888-89..	0.35	2.82	1.49	3.47	2.85	0.77	0.14	0.09	0.00	0.06	0.62	0.29	12.95
1889-90...	0.61	1.31	0.73	5.31	0.89	1.37	0.96	0.55	0.00	0.00	1.10	1.55	14.38
1890-91...	0.26	1.07	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mean....	0.94	0.45	0.81	1.76	1.06	1.24	0.74	0.42	0.13	0.12	1.26	1.48	10.39

Record of precipitation at Fort Apache, Navajo County.

Latitude 33° 48′, longitude 109° 57′; elevation, 5,050 feet. Authority, Signal Service and United States Hospital Service.

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76...	.....	.....	.....	.....	0.92	1.72	2.02	0.08	0.26	1.02	5.20	2.52	.....
1876-77...	2.00	2.44	1.34	0.22	0.36	0.94	0.72	0.96	1.15	0.00	3.11	1.20	14.44
1877-78...	0.99	0.81	0.19	2.07	0.18	1.35	2.41	1.77	0.18	0.79	8.76	9.33	28.83
1878-79...	0.76	0.00	1.94	1.14	1.89	1.17	0.03	0.12	0.00	0.05	3.92	3.06	14.08
1879-80...	1.52	2.64	1.77	2.41	1.31	0.95	0.80	0.46	0.00	0.46	5.83	1.44	19.59
1880-81...	0.55	0.56	0.03	2.38	0.20	1.17	2.45	1.53	0.35	T.	5.63	8.31	23.16
1881-82...	5.41	4.68	0.85	0.54	2.82	2.85	1.09	0.91	0.94	3.27	4.79	7.36	35.51
1882-83...	1.02	T.	2.34	0.23	0.85	2.46	2.03	0.22	0.86	0.02	5.46	4.26	19.75
1883-84...	0.60	1.39	0.02	3.48	0.68	3.43	4.44	1.67	1.31	2.35	0.14	5.59	25.10
1884-85...	1.50	2.02	0.82	5.52	0.52	1.00	2.05	0.52	1.12	0.82	2.60	3.16	21.65
1885-86...	0.44	0.38	1.56	1.41	3.90	2.73	1.06	0.91	0.00	0.19	1.90	4.75	19.23
1886-87...	3.16	1.66	0.56	0.24	0.59	2.16	0.04	0.81	0 15	1.70	3.29	3.92	18.28
1887-88...	2.23	0.55	1.83	0.57	1.42	1.83	2.92	0.71	0.71	T.	3.24	[1.00]	17.01
1888-89...	0.32	1.23	2.63	2.88	2.24	0.88	1.85	0.47	0.00	0.11	2.67	2.87	18.15
1889-90...	1.02	0.46	0.55	3.98	2.26	2.40	0.82	1.39	0.00	0.00	5.00	4.44	22.32
1890-91...	2.37	2.17	2.85	3.02	1.65	4.10	0.85	T.	0.36	T.	2.72	1.22	21.31
1891-92...	1.81	0.00	0.00	0.65	0.65	2.29	2.22	1.36	0.36	0.15	1.33	1.30	12.12
1892-93...	1.23	0.55	0.57	0.69	0.28	1.10	2.45	0.00	2.18	0.00	2.57	3.43	15.05
1893-94...	2.65	0.04	0.28	0.10	1.24	0.96	1.36	0.19	0.79	0.00	1.27	5.01	13.89
1894-95...	1.32	2.47	0.00	2.81	1.89	0.72	0.02	T.	1.00	0.01	0.74	5.44	16.42
1895-96...	1.68	3.02	2.39	1.12	0.16	0.33	0.86	0.34	0.00	0.52	4.31	4.36	19.09
Mean..	1.63	1.35	1.13	1.77	1.23	1.74	1.55	0.69	0.56	0.55	3.55	4.00	19.75

Record of precipitation at Pinal Ranch, Pinal County.

[Latitude 33° 25′, longitude 110° 58′; elevation, 4,400 feet. Authority, Irion and Craig.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1891-92...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.00	0.81	.....
1892-93...	0.15	0.90	0.43	0.99	0.92	1.57	5.21	0.00	1.44	0.00	2.86	3.69	18.16
1893-94...	4.13	0.00	1.66	0.83	1.23	1.81	1.93	0.00	0.14	0.00	1.63	2.87	16.23
1894-95...	0.32	1.19	0.00	7.77	7.28	1.06	0.31	0.00	0.36	0.00	0.63	5.88	24.80
1895-96...	2.04	4.78	5.33	1.52	1.10	0.18	1.05	0.50	0.00	0.24	4.04	2.90	23.69
1896-97...	3.47	3.42	2.35	1.13	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mean..	2.02	2.06	1.95	2.45	2.63	1.16	2.13	0.13	0.48	0.06	1.83	3.23	20.46

Record of precipitation at Phœnix, Maricopa County.

[Latitude 33° 28′, longitude 112° 00′; elevation, 1,068 feet. Authority, Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76...	.....	.....	.....	.....	.....	0.82	0.27	0.00	0.00	.....	.....	[1.00]	.....
1876-77...	0.90	0.72	0.00	0.00	0.60	1.63	0.31	0.00	0.00	0.00	[1.00]	0.02	5.18
1877-78...	1.11	0.04	0.03	0.43	0.07	1.07	0.96	1.25	0.04	0.00	2.40	1.63	9.03
1878-79...	0.19	0.00	0.27	0.64	0.07	0.75	0.33	0.07	0.00	0.00	0.54	0.67	3.53
1879-80...	0.69	0.27	1.66	1.35	1.16	0.38	0.26	0.15	0.00	0.49	1.18	0.72	8.31
1880-81...	0.67	0.20	0.00	1.61	0.00	0.30	1.46	1.10	0.12	0.00	2.03	2.19	9.58
1881-82...	1.04	0.25	0.36	0.16	1.62	0.17	0.00	0.00	0.00	0.37	0.32	1.81	6.10
1882-83...	1.25	0.10	1.30	0.00	0.83	1.27	1.16	T.	0.44	0.00	0.07	0.07	6.49
1883-84...	0.00	0.20	0.00	3.36	0.16	2.46	2.14	0.40	0.01	0.15	0.07	1.84	10.79
1884-85 ..	1.50	1.12	0.24	2.74	0.00	0.47	0.33	0.00	0.65	0.04	0.18	0.71	7.98
1885-86...	0.07	0.09	0.91	0.32	1.32	1.25	1.86	0.29	0.00	0.00	0.05	0.59	6.75
1886-87...	0.45	0.58	0.32	0.07	0.00	0.28	T.	0.75	0.06	0.00	.....	.....	.....
1887-88...	.....	.....	.....	[0.50]	.....	.....	.....	0.01	0.30	0.00	0.13	0.27	.....
1888-89...	0.23	[2.80]	1.10	[3.00]	.....	.....	.....	.....	0.00	0.12	0.66	1.77	.....
1889-90...	0.39	0.99	0.77	3.38	0.95	0.52	1.18	0.51	0.00	.....	.....	.....	.....
1891-92...	.....	.....	0.00	0.13	1.85	2.20	0.60	0.70	0.15	0.00	0.00	0.00	.....
1892-93...	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	1.00	0.00	3.20	[1.42]	6.08
1893-94...	0.00	0.00	0.60	1.00	0.00	0.70	0.62	0.00	0.07	0.00	0.97	0.79	4.75
1894-95...	0.15	0.77	0.00	1.43	.....	.....	.....	0.00	.....	.....	.....	.....	.....
1895-96...	.....	.....	1.22	0.07	0.48	0.00	0.28	0.00	0.00	0.00	3.66	1.05	.....
Mean..	0.54	0.51	0.48	1.44	0.57	0.83	0.72	0.29	0.15	0.07	1.03	0.97	7.60

Record of precipitation at Fort Bowie, Cochise County.

[Latitude 32° 12′, longitude 109° 20′; elevation, 4,781 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1866-67...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.67	.....
1867-68...	1.70	T.	0.50	1.64	2.39	1.10	0.00	0.70	0.50	0.00	7.15	2.40	18.08
1868-69...	3.15	T.	0.70	0.00	0.10	3.50	0.39	0.15	0.00	0.40	1.30	5.60	15.29
1869-70...	0.20	T.	1.45	0.15	0.30	0.69	0.50	T.	0.00	0.60	4.50	5.42	13.81
1870-71...	1.00	0.00	T.	1.00	0.50	[1.00]	[0.50]	[0.60]	0.18	0.60	7.90	2.30	15.58
1871-72...	1.00	0.70	0.90	[1.25]	[0.40]	[0.50]	0.00	0.25	0.20	1.04	1.67	3.36	11.27
1872-73...	0.77	T.	0.15	2.95	0.00	1.16	2.22	T.	1.09	0.14	0.50	1.34	10.32
1873-74...	0.01	0.03	1.12	2.02	2.33	5.40	1.50	0.35	0.00	T.	2.66	3.12	18.54
1874-75...	0.06	1.40	1.45	0.46	1.35	1.20	0.13	0.13	T.	0.65	4.22	1.77	12.82

Record of precipitation at Fort Bowie, Cochise County—Continued.

Latitude 32° 12′, longitude 109° 20′; elevation, 4,781 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76...	3.19	0.00	0.25	0.83	0.60	0.45	0.48	T.	T.	2.05	4.55	4.00	16.40
1876-77...	1.95	0.73	0.40	0.00	0.14	2.70	0.12	0.14	0.90	0.00	1.24	0.18	8.50
1877-78...	1.16	0.00	0.00	2.04	[0.50]	0.50	2.83	1.00	0.20	0.20	4.92	7.44	20.79
1878-79...	0.07	0.07	1.50	1.09	3.00	0.63	0.40	0.02	0.00	0.60	1.01	0.20	7.99
1879-80...	2.00	0.60	0.10	0.50	0.25	1.40	1.45	0.15	0.00	1.50	4.80	0.97	13.72
1880-81...	1.35	0.70	0.05	0.82	0.00	0.20	0.79	0.05	0.10	0.06	5.53	5.16	14.81
1881-82...	2.27	1.15	0.58	0.03	0.90	1.15	1.51	0.26	0.71	1.39	3.58	4.84	18.37
1882-83...	1.51	[0.00]	1.79	0.35	1.49	1.33	2.84	0.00	1.50	0.33	2.21	1.73	15.08
1883-84...	0.72	0.20	0.39	1.12	3.14	4.96	2.63	0.00	0.23	0.12	0.65	2.44	16.60
1884-85...	0.62	3.58	0.42	6.41	0.53	1.81	2.19	0.00	0.19	0.66	1.83	2.19	20.43
1885-86...	0.44	0.00	1.42	1.74	4.24	4.88	4.48	0.07	0.01	4.21	2.24	2.49	26.22
1886-87...	1.26	0.36	0.74	0.15	0.13	2.11	0.00	0.23	T.	1.30	4.49	5.51	16.28
1887-88...	2.71	1.01	1.10	1.94	1.11	1.50	1.92	T.	0.46	0.53	2.50	1.37	16.15
1888-89...	0.21	1.89	1.95	2.12	1.38	1.62	1.58	T.	0.09	0.09	2.65	0.20	13.78
1889-90...	3.37	0.74	T.	0.51	0.78	0.23	0.03	0.59	0.00	T.	4.97	4.06	15.28
1890-91...	1.74	1.60	0.61	2.45	0.69	2.18	0.65	0.00	1.38	T.	0.28	1.00	12.58
1891-92...	0.61	0.00	0.00	1.26	0.81	3.36	1.62	0.41	0.00	0.50	1.12	2.65	12.34
1892-93...	0.00	1.80	0.30	0.60	0.40	0.80	2.70	0.00	0.30	0.00	3.69	3.41	14.00
1893-94...	1.06	0.04	0.07	0.25	0.65	2.55	1.07	0.01	T.	T.	1.07	4.80	11.57
1894-95...	1.06	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mean..	1.26	0.59	0.66	1.25	1.04	1.81	1.28	0.19	0.30	0.61	3.08	3.95	16.02

Record of precipitation at Wilcox, Cochise County.

[Latitude 32° 20′, longitude 109° 42′; elevation, 4,164 feet. Authority, Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1880-81...	.....	0.04	0.00	0.40	0.02	0.00	2.95	T	0.00	[0.00]	3.97	5.17	12.55
1881-82...	0.00	0.00	0.00	0.00	[0.50]	1.15	0.30	0.00	0.00	[0.90]	0.11	3.46	6.22
1882-83...	1.56	0.00	0.58	0.32	1.25	0.31	0.41	0.00	0.33	0.03	1.56	3.15	9.50
1883-84...	0.04	0.30	0.36	0.99	0.80	1.61	1.75	0.00	0.00	0.04	1.17	1.54	8 60
1884-85...	0.14	3.59	0.25	3.49	0.05	0.63	1.52	0.03	[0.20]	0.34	1.78	2.10	14.12
1885-86...	1.11	0.00	0.56	0.19	[3.00]	[1.00]	0.15	0.01	0.00	T.	0.37	2.14	8.53
1886-87...	1.68	0.36	0.58	0.08	T.	1.83	0.00	0.03	0.48	0.47	3.82	5.31	14.64
1887-88...	2.96	0.45	0.22	0.92	0.36	1.21	1.13	0.03	0.14	0.08	3.68	0.42	11.60
1888-89...	0.50	1.15	1.86	1.37	1.31	0.90	1.03	0.04	0.00	0.13	4.91	0.97	14.20
1889-90...	2.91	0.83	T.	0.62	1.61	0.35	0.22	0.63	0.00	0.14	2.64	5.20	15.15
1890-91...	1.97	0.54	0.43	0.72	0.54	2.45	0.26	0.00	0.87	0.07	T.	2.10	9.95
1891-92...	0.22	0.00	0.00	0.85	0.05	1.45	0.84	0.25	1.02	2.00	0.97	0.94	8.59
1892-93...	0.32	0.00	0.00	0.17	0.00	0.10	0.79	0.00	0.50	0.00	1.74	1.03	4.65
1893-94...	0.93	0.00	0.00	0.00	0.50	1.37	0.77	0.00	0.00	0.00	0.00	1.52	5.09
1894-95...	0.27	0.78	0.00	0.67	0.11	0.00	0.00	0.00	0.77	0.00	1.92	3.06	7.58
1895-96...	0.11	0.08	1.59	0.40	0.27	1.03	0.05	0.00	0.00	0.00	1.46	1.77	6.76
Mean..	0.98	0.51	0.40	0.70	0.65	0.96	0.74	0.06	0.27	0.26	1.88	2.49	9.90

Record of precipitation at Fort Grant, Graham County.

[Latitude 32° 36′, longitude 109° 53′; elevation, 4,860 feet. Authority, Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1872-73...	.....	.....	.....	.....	0.00	0.10	1.00	0.09	0.50	1.40	1.70	5.20	9.90
1873-74...	2.50	0.46	3.38	1.75	1.58	2.87	2.45	0.58	0.07	0.00	2.70	2.01	20.35
1874-75...	0.00	1.47	0.30	3.78	2.48	1.44	1.95	1.52	0.00	0.50	7.02	1.08	21.54
1875-76...	4.59	0.01	0.20	0.12	0.26	0.24	0.44	.....	.....	0.65	5.27	7.41	.....
1876-77...	1.99	2.86	1.00	[1.42]	0.17	1.50	0.30	0.42	0.66	0.00	0.94	0.60	11.86
1877-78...	2.88	0.50	0.00	2.16	0.23	0.50	0.37	0.18	0.00	0.32	6.44	4.93	18.51
1878-79...	0.20	0.00	1.90	1.39	1.38	0.47	0.85	0.07	0.00	0.08	2.59	1.12	10.05
1879-80...	2.18	1.83	0.87	1.38	0.60	0.48	0.85	0.08	0.00	1.32	5.63	3.73	18.95
1880-81...	1.01	0.47	0.00	1.57	0.05	0.33	0.89	0.84	0.26	T.	5.53	5.47	16.42
1881-82...	3.84	1.02	0.08	0.65	0.86	1.26	1.84	0.07	0.81	1.47	2.62	4.73	19.25
1882-83...	0.80	0.00	0.79	0.17	1.21	1.40	1.27	0.03	1.16	1.26	2.90	3.07	14.06
1883-84...	0.42	1.21	0.11	1.44	1.12	4.62	3.87	0.47	0.81	1.20	0.67	2.41	18.35
1884-85...	0.98	3.06	0.53	5.93	0.31	1.02	1.40	0.04	0.25	0.73	0.93	1.58	16.76
1885-86...	0.81	0.03	1.30	0.81	2.46	1.29	0.53	0.30	0.04	0.57	2.79	3.40	14.33
1886-87...	3.49	0.57	0.10	0.09	0.11	2.58	T.	0.36	0.16	0.85	9.00	6.20	23.51
1887-88...	4.20	0.37	0.28	0.21	0.12	0.44	0.83	0.50	0.18	0.02	4.27	0.52	11.94
1888-89...	0.78	1.19	3.67	1.68	1.99	1.28	1.04	0.13	T.	1.06	3.57	1.35	17.74
1889-90...	0.69	0.94	0.16	1.11	1.58	0.46	0.46	0.92	0.01	0.20	3.23	4.54	14.30
1890-91...	0.69	1.62	0.16	2.01	0.82	3.78	0.28	0.00	1.40	0.10	1.19	2.25	14.30
1891-92...	1.21	0.00	0.00	1.18	0.96	1.59	1.66	0.64	0.35	0.00	0.86	1.00	9.45
1892-93...	0.11	0.46	0.12	0.15	0.56	0.59	1.26	0.00	0.58	0.00	4.24	2.00	10.07
1893-94...	3.87	T	0.40	0.35	0.38	3.43	0.66	0.13	0.37	0.00	2.55	1.98	14.12
1894-95...	0.14	1.10	0.00	2.79	1.65	0.37	0.02	0.07	0.30	0.14	1.09	4.02	11.69
1895-96...	1.69	1.21	2.05	0.61	0.29	0.50	0.34	0.26	0.00	0.90	1.88	2.68	12.41
Mean..	1.70	0.89	0.76	1.42	0.88	1.36	1.02	0.33	0.34	0.53	3.32	3.05	15.45

Record of precipitation at Fort Thomas, Graham County.

[Latitude 33° 04′, longitude 109° 51′; elevation, 2,700 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1879-80...	.....	.....	.....	.....	.....	.....	.....	0.06	0.00	0.55	0.87	2.49	.....
1880-81...	0.55	0.18	0.03	1.27	0.03	0.13	1.21	0.63	0.07	0.00	4.18	2.49	10.77
1881-82...	1.55	0.40	0.32	0.40	0.33	1.01	0.70	0.02	0.47	1.26	0.88	2.48	9.82
1882-83...	0.28	0.00	0.77	0.46	1.23	1.54	1.33	0.00	0.79	0.00	1.85	2.52	10.77
1883-84...	T.	0.52	0.00	1.07	0.45	2.94	3.21	0.72	0.60	0.52	0.36	2.04	12.43
1884-85...	0.91	0.69	0.56	5.16	0.03	1.00	0.75	0.14	0.09	0.18	2.93	2.46	14.90
1885-86...	0.02	0.01	0.38	0.71	2.16	1.40	0.44	0.24	0.00	0.00	0.10	4.02	9.48
1886-87...	1.18	1.12	0.16	0.04	0.09	0.84	0.00	0.31	2.73	0.35	3.78	2.53	13.13
1887-88...	3.87	0.28	0.52	1.05	0.65	1.06	1.78	0.37	0.23	0.00	1.88	0.64	12.33
1888-89...	0.55	2.80	1.72	1.66	1.47	1.35	0.96	0.10	0.00	T.	3.45	1.40	15.46
1889-90...	0.38	0.26	0.34	1.18	1.92	0.49	0.45	1.21	0.00	T.	2.02	4.11	12.36
1890-91...	0.75	1.30	0.69	0.99	0.72	2.98	0.40	0.00	1.61	0.18	.....	.....	.....
Mean..	0.91	0.69	0.50	1.27	0.83	1.34	1.02	0.32	0.55	0.25	2.03	2.47	12.18

Record of precipitation at San Carlos, Gila County.

[Latitude 33° 12′, longitude 110° 27′; elevation, 3,456 feet. Authority, Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1880-81...	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.00	4.13	5.93	.....
1881-82...	1.94	0.93	0.06	0.52	1.24	0.93	0.55	0.00	0.71	1.09	1.98	6.05	16.00
1882-83...	0.58	0.00	1.58	0.66	1.60	2.07	0.71	0.00	0.53	0.00	2.48	1.11	11.32
1883-84...	0.11	1.13	0.00	2.47	1.00	3.83	3.97	0.84	0.32	0.49	0.37	1.24	15.77
1884-85...	0.83	1.49	0.55	5.48	0.05	1.39	1.28	0.03	0.22	0.47	1.25	1.22	14.26
1885-86...	0.34	0.34	0.70	0.90	2.88	1.29	0.82	0.14	0.00	0.00	0.03	3.49	10.93
1886-87...	0.87	0.46	0.46	0.00	T.	1.12	0.00	0.23	0.06	0.31	2.49	1.56	7.56
1887-88...	0.88	0.08	[0.50]	1.45	0.52	1.03	1.93	0.00	0.10	0.00	2.10	0.40	8.99
1888-89...	0.63	1.73	1.76	2.84	1.62	1.33	2.15	0.25	0.00	T.	1.83	0.87	15.01
1889-90...	2.05	0.60	0.40	2.30	2.11	1.66	1.03	1.31	0.00	0.00	2.25	3.41	17.12
1890-91...	0.89	1.22	2.12	2.63	0.75	5.25	0.47	0.00	0.77	0.00	0.57	1.00	15.67
1891-92...	0.75	0.00	0.00	1.44	1.80	3.51	1.22	1.03	0.08	0.00	1.30	1.90	13.03
1892-93...	0.00	0.65	0.34	0.22	0.50	0.55	2.96	0.00	0.67	0.00	0.80	3.78	10.47
1893-94...	2.56	0.00	0.34	0.37	0.63	1.37	1.14	0.11	0.31	0.00	0.81	2.06	9.70
1894-95...	0.09	1.05	0.00	2.58	2.16	0.45	0.18	0.00	0.04	0.05	0.32	2.39	9.31
1895-96...	1.94	3.01	3.42	0.45	0.43	0.04	0.50	T.	0.00	T.	3.78	0.88	14.45
Mean..	0.96	0.85	0.82	1.62	1.15	1.72	1.26	0.26	0.25	0.15	1.66	2.33	13.03

Record of precipitation at Benson, Cochise County.

[Latitude 32° 00′, longitude 110° 22′; elevation, 3,580 feet. Authority, Pacific Railway System.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1880-81...	[0.71]	0.00	0.00	[1.50]	0.00	0.00	0.75	0.00	0.00	0.02	2.17	4.33	9.48
1881-82...	0.99	0.34	0.00	0.00	0.40	1.20	0.00	0.00	0.00	0.86	2.00	3.58	9.37
1882-83...	0.65	0.00	0.80	0.15	0.65	0.63	2.08	0.00	0.42	0.16	2.97	2.78	11.29
1883-84...	0.10	0.21	0.07	0.50	0.20	0.63	1.20	T.	0.00	0.00	0.70	0.27	3.88
1884-85...	0.30	2.89	T.	2.50	0.05	0.95	0.07	0.00	0.00	0.75	0.58	1.44	9.53
1885-86...	0.14	0.00	0.09	0.17	0.79	0.67	0.08	0.00	0.00	0.00	1.44	2.68	6.06
1886-87...	0.17	0.25	0.00	0.19	0.00	0.34	0.00	T.	0.08	0.00	1.49	2.39	4.91
1887-88...	2.92	0.45	0.37	0.15	0.04	0.00	0.30	0.00	0.37	0.00	2.44	1.66	8.70
1888-89...	0.05	0.84	1.11	1.03	0.93	0.07	0.63	0.00	0.00	0.63	2.16	0.94	8.39
1889-90...	1.04	0.05	0.00	1.33	1.94	0.00	0.00	0.23	0.00	0.52	[2.50]	4.81	12.42
1890-91...	1.44	0.41	0.50	1.48	0.38	1.31	0.15	0.00	[0.00]	[0.25]	1.19	1.81	8.92
1891-92...	0.34	0.00	0.00	0.38	0.40	1.30	0.40	0.42	0.00	0.00	0.00	0.07	3.31
1892-93...	0.03	0.00	0.00	[0.63]	0.00	0.00	[0.92]	0.00	0.76	0.00	2.88	3.03	8.25
1893-94...	0.12	0.00	0.00	0.00	T.	1.50	0.40	0.00	0.00	0.10	1.65	2.03	5.80
1894-95...	0.95	0.00	0.00	0.74	0.00	0.00	[0.47]	0.00	1.00	0.00	0.13	1.20	4.49
1895-96...	1.40	0.00	0.00	0.00	0.10	0.00	0.12	0.00	0.00	0.00	0.00	0.60	4.77
Mean..	0.71	0.34	0.18	0.63	0.36	0.54	0.47	0.04	0.16	0.21	1.68	2.10	7.42

Record of precipitation at Tucson, Pima County.

[Latitude 32° 14′, longitude 110° 54′; elevation, 2,404 feet. Authority, Pacific Railway System and E. L. Wetmore.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76...	.....	.....	0.18	0.82	0.37	0.25	1.22	0.00	0.00	0.29	3.71	4.19	.....
1876-77...	2.28	0.96	0.75	0.00	0.19	2.53	0.20	0.57	0.41	0.00	3.04	0.02	10.95
1877-78...	2.44	0.46	0.00	2.91	0.22	1.00	1.77	0.52	0.00	0.65	5.72	4.71	20.40
1878-79...	0.08	0.00	1.31	0.68	2.02	0.94	0.83	0.02	0.00	0.01	0.84	1.76	8.49
1879-80...	0.74	0.94	0.60	3.31	0.56	0.15	0.41	0.04	0.00	T.	1.62	1.28	9.65
1880-81...	1.89	0.09	0.00	0.57	0.05	0.25	1.17	0.62	0.04	0.00	5.69	3.92	14.29
1881-82...	2.37	0.62	0.00	0.19	1.75	1.64	0.72	0.05	0.01	0.99	2.63	6.32	17.29
1882-83...	0.32	0.00	1.12	0.04	1.27	0.51	1.14	T.	0.35	0.08	2.20	1.40	8.43
1883-84...	0.10	0.65	0.02	0.06	0.83	2.59	1.91	0.17	0.23	0.23	0.32	1.15	8.26
1884-85...	0.30	2.24	0.34	4.72	0.00	0.42	0.40	0.00	0.00	0.13	1.00	1.76	11.31
1885-86...	0.12	0.00	0.42	1.01	1.61	0.36	0.87	0.06	0.00	0.00	1.06	2.47	7.98
1886-87...	[1.00]	0.31	0.45	0.40	0.00	0.85	0.00	0.38	0.32	0.26	5.08	1.25	10.30
1887-88...	2.08	1.72	0.74	0.27	0.73	0.57	1.03	T.	0.32	0.55	1.58	0.92	10.51
1888-89...	0.10	0.78	2.06	1.96	1.74	1.06	1.98	0.18	T.	0.30	5.66	2.06	17.88
1889-90...	3.12	0.36	0.32	1.59	1.27	0.76	0.29	0.10	0.00	0.00	2.37	5.13	15.31
1890-91...	1.44	0.65	0.83	1.32	0.12	2.08	0.17	0.00	0.18	0.22	0.70	2.26	9.97
1891-92...	0.65	0.00	0.00	0.23	1.66	2.54	1.01	0.26	0.36	0.21	2.19	1.84	10.95
1892-93...	0.61	0.32	0.00	0.25	0.27	0.88	1.16	T.	1.09	0.00	2.44	5.65	12.67
1893-94...	0.96	T.	0.40	0.41	0.11	1.04	1.17	T.	0.05	T.	1.60	1.01	6.75
1894-95...	0.12	0.31	0.00	1.88	0.56	T.	0.00	T.	0.09	0.02	0.11	5.35	8.44
1895-96...	0.75	0.68	4.30	0.08	0.53	0.10	0.27	0.12	T.	0.19	3.45	1.25	11.72
Mean..	1.07	0.55	0.66	1.08	0.76	0.98	0.84	0.15	0.16	0.20	2.52	2.65	11.62

Record of precipitation at Casa Grande, Pinal County.

[Latitude 32° 54′, longitude 111° 40′; elevation, 1,308 feet. Authority, Pacific Railway System.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1880-81...	[0.45]	0.05	0.00	[1.00]	0.00	0.00	[1.00]	0.73	0.00	0.00	0.00	T.	3.23
1881-82...	0.00	0.00	0.00	0.00	[2.00]	[0.80]	0.00	0.00	0.00	[0.10]	0.00	0.00	2.90
1882-83...	0.00	0.00	[0.35]	0.00	0.00	0.00	0.00	0.60	0.24	0.00	[1.00]	0.81	2.40
1883-84...	0.00	0.10	0.00	0.86	0.75	[1.00]	1.08	0.00	0.00	0.00	0.00	2.37	6.16
1884-85...	0.00	1.31	0.00	3.20	0.00	0.30	0.10	0.00	0.00	0.00	0.75	0.64	6.30
1885-86...	0.00	0.00	0.23	0.00	0.90	[1.25]	0.74	0.09	0.00	0.00	0.33	1.46	5.00
1886-87...	0.00	0.00	0.35	0.00	0.00	0.40	0.00	0.30	0.20	0.40	1.07	0.97	3.69
1887-88...	1.99	0.95	1.28	0.15	0.61	0.00	0.45	0.00	[0.10]	0.00	0.28	0.00	5.81
1888-89...	0.41	[1.00]	0.70	0.75	[1.00]	0.00	0.50	0.10	0.00	0.00	0.00	0.00	4.46
1889-90...	0.50	0.80	0.10	1.25	0.30	0.61	0.41	0.38	0.00	0.00	1.38	3.41	9.14
1890-91...	0.96	0.38	2.00	0.87	0.65	1.90	0.00	0.00	0.00	0.00	0.90	0.00	7.66
1891-92...	0.00	0.00	0.00	0.17	3.25	2.35	0.65	0.00	0.34	0.00	0.23	0.64	7.63
1892-93...	0.00	0.15	0.00	1.14	0.06	0.00	1.87	0.00	0.07	0.00	1.72	0.95	5.96
1893-94...	0.00	0.00	0.00	0.25	0.00	0.10	0.02	0.00	0.07	0.00	0.67	0.81	2.52
1894-95...	0.89	0.13	0.00	2.53	0.45	0.00	0.00	0.00	0.00	0.00	0.35	1.30	5.65
1895-96...	2.00	1.60	0.60	.....	0.65	0.00	0.10	0.00	0.00	0.00	.....	0.88	.....
Mean..	0.45	0.40	0.35	0.81	0.66	0.54	0.47	0.10	0.06	0.03	0.58	0.89	5.34

Record of precipitation at Maricopa, Pinal County.

[Latitude 33° 05′, longitude 112° 00′; elevation, 1,190 feet. Authority, Pacific Railway System and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76...	.....	.....	0.00	0.00	0.72	0.27	0.39	0.00	0.00	0.45	0.44	1.09	.....
1876-77...	0.00	0.10	0.41	0.00	0.08	1.57	0.30	0.03	0.41	0.00	1.26	0.00	4.16
1877-78...	1.07	0.00	0.01	1.54	0.00	1.01	.....	.....	.....	.....	.....	.....	.....
1878-79...	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.00	0.10	1.81	.....
1879-80...	0.38	0.04	0.85	0.80	1.45	0.16	0.00	0.75	0.00	0.00	0.00	0.00	4.43
1880-81...	0.50	0.00	0.00	0.50	0.00	0.00	0.88	0.00	0.00	0.00	0.00	1.47	3.35
1881-82...	0.50	0.00	0.00	0.00	T.	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.88
1882-83...	0.00	0.00	0.00	0.00	1.34	0.00	0.00	0.00	0.00	0.00	0.50	3.57	5.41
1883-84...	0.30	0.00	0.00	1.96	0.38	0.74	2.83	0.51	0.01	0.32	0.53	0.86	8.44
1884-85...	1.10	1.51	0.20	2.97	0.00	0.45	0.15	0.00	0.18	0.04	0.48	0.92	8.00
1885-86...	T.	0.00	0.56	0.19	1.32	1.65	1.71	0.06	0.00	0.00	0.16	0.08	5.73
1886-87...	0.06	0.76	0.21	0.11	0.00	0.17	T.	0.51	0.31	0.03	0.43	0.50	3.09
1887-88...	1.00	0.28	1.13	0.00	0.00	0.12	0.48	0.00	0.00	0.00	0.80	0.22	4.03
1888-89...	0.35	0.52	0.75	0.70	0.85	0.15	1.19	0.00	0.00	0.00	0.55	0.90	5.96
1889-90...	0.90	1.20	0.83	3.00	0.00	0.22	1.02	0.00	0.00	0.00	0.10	4.29	11.56
1890-91...	0.15	0.07	0.31	2.47	0.02	2.33	0.00	0.01	0.00	0.00	0.13	0.39	5.88
1891-92...	0.13	0.00	0.00	0.00	1.55	2.44	0.50	0.40	0.14	0.00	0.62	0.25	6.03
1892-93...	0.15	0.00	0.00	0.00	1.26	0.00	1.14	0.00	0.64	0.00	0.68	0.50	4.37
1893-94...	2.08	0.00	0.30	0.00	0.32	0.12	0.50	0.00	0.00	0.00	0.38	1.96	5.66
1894-95...	0.35	0.50	0.00	2.44	0.61	0.00	0.00	0.00	0.00	0.00	0.93	0.85	5.68
1895-96...	1.10	1.10	1.48	0.00	0.68	0.00	0.22	0.00	0.00	0.03	1.18	0.27	6.06
Mean..	0.53	1.01	0.35	0.83	0.52	0.57	0.60	0.12	0.81	0.04	0.46	1.01	6.85

Record of precipitation at Texas Hill, Yuma County.

[Latitude 32° 44′, longitude 113° 38′; elevation, 355 feet. Authority, Pacific Railway System.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July	Aug.	Total.
1879-80...	0.05	0.55	0.43	0.47	0.23	0.00	0.00	0.06	0.00	0.00	0.00	0.00	1.79
1880-81...	0.35	0.00	0.00	0.34	0.00	0.00	0.24	0.56	0.00	0.00	0.03	0.24	1.76
1881-82...	0.12	2.50	0.00	0.18	1.87	0.00	0.00	0.00	0.00	0.00	0.00	0.53	5.20
1882-83...	[0.00]	0.05	0.12	0.00	0.19	0.14	0.20	0.03	0.00	0.00	0.68	0.70	2.11
1883-84...	0.00	0.09	[0.00]	1.05	0.22	1.21	1.75	0.28	0.28	0.00	0.00	0.00	4.88
1884-85...	0.02	0.00	0.00	1.26	0.00	0.04	0.02	0.00	0.00	0.00	0.00	2.25	3.59
1885-86...	0.00	0.00	0.32	0.00	0.93	1.15	0.00	0.20	0.00	0.00	T.	0.95	3.55
1886-87...	0.00	1.50	0.00	0.00	0.00	0.01	0.00	T.	0.00	0.00	T.	T.	1.51
1887-88...	2.89	0.00	1.40	0.05	0.25	0.00	0.63	0.00	0.00	0.00	0.08	0.00	5.30
1888-89...	[0.30]	1.94	[0.50]	1.29	2.65	0.00	0.12	0.00	0.00	0.00	T.	0.00	6.80
1889-90...	0.00	0.10	0.05	0.62	0.00	0.40	0.00	0.00	0.00	0.00	0.10	[0.50]	1.77
1890-91...	0.10	0.03	0.10	1.28	0.00	2.50	0.00	0.00	0.00	0.00	0.11	0.65	4.77
1891-92...	0.20	0.00	0.00	[0.05]	1.64	.....	.....	.....	0.00	0.00	0.00	0.00	.....
1892-93...	0.00	0.00	0.00	0.00	0.00	0.00	[1.50]	0.00	0.00	0.00	0.40	0.00	1.90
1893-94...	0.00	0.00	0.00	0.00	.....	.....	.....	.....	.....	.....	.....	.....	.....
1894-95...	.....	.....	.....	.....	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.....
1895-96...	0.00	0.00	0.10	0.00	0.00	0.00	0.75	0.00	0.00	0.00	1.15	1.20	3.20
Mean..	0.25	0.42	0.18	0.41	0.50	0.36	0.35	0.08	0.02	0.00	0.16	0.43	3.16

Record of precipitation at Yuma, Yuma County.

[Latitude 32° 44', longitude 114° 36'; elevation, 141 feet. Authority, Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76...	[0.17]	T.	0.00	0.00	0.44	0.46	0.04	0.00	0.00	0.00	0.00	0.00	1.11
1876-77...	0.00	0.00	0.00	0.00	0.09	1.72	0.00	0.00	0.00	0.00	0.50	0.06	2.43
1877-78...	T.	0.00	0.00	1.23	0.00	0.06	0.13	0.02	0.00	0.00	0.55	1.59	3.58
1878-79...	0.37	0.00	0.02	0.14	0.59	1.21	0.48	0.15	0.00	0.00	0.00	0.00	2.96
1879-80...	0.11	0.33	0.15	0.27	T.	T.	0.00	T.	0.00	0.00	T.	T.	0.86
1880-81...	T.	T.	0.00	0.74	0.00	0.00	T.	0.55	0.00	T.	0.20	0.08	1.57
1881-82...	0.05	T.	0.00	0.10	1.35	0.01	0.00	0.00	0.00	0.05	0.20	0.03	1.79
1882-83...	0.04	0.01	0.09	0.00	0.96	0.68	T.	T.	0.00	0.00	0.31	0.22	2.31
1883-84...	0.13	0.05	0.00	[1.61]	T.	1.58	1.48	0.07	0.44	T.	0.01	0.32	5.69
1884-85...	T.	T.	T.	1.96	T.	0.02	T.	0.07	T.	0.00	0.05	0.86	2.96
1885-86...	0.00	0.00	1.71	0.01	1.06	0.08	0.33	0.31	0.00	0.00	T.	2.23	5.73
1886-87...	0.00	1.11	0.23	0.00	0.00	T.	0.00	0.20	T.	0.01	T.	T.	1.55
1887-88...	1.09	0.02	2.43	0.15	0.18	0.05	0.05	T.	0.00	0.00	0.04	T.	4.01
1888-89...	0.01	0.99	0.68	0.95	1.12	0.06	0.24	0.00	0.00	T.	T.	0.25	4.30
1889-90...	0.00	0.59	T.	2.43	T.	0.86	T.	0.37	0.43	0.00	0.00	0.67	5.35
1890-91...	0.64	.....	.....	.....	0.00	2.53	T.	0.00	T.	0.00	0.04	0.05	.....
1891-92...	T.	0.00	0.00	0.05	1.85	0.87	0.52	T.	0.05	0.00	0.00	0.02	3.36
1892-93...	0.04	0.00	0.00	T.	T.	[0.57]	1.53	0.00	0.31	0.00	0.40	0.42	3.27
1893-94...	0.30	0.00	0.30	0.11	0.00	T.	0.74	0.00	T.	0.00	0.36	0.10	1.91
1894-95...	0.51	0.84	0.00	0.40	0.77	.....	.....	.....	.....	.....	.....	.....	.....
Mean..	0.17	0.21	0.30	0.53	0.42	0.57	0.29	0.09	0.07	.....	0.14	0.36	3.15

Miscellaneous rainfall observations in Arizona, 1896.

Stations.	Elevation.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Buttes.	1,600	0.60	0.16	0.77	0.12	0.00	0.00	3.10	0.90	1.69	1.27	0.67	1.09	10.43
Pinal ..	2,550	.....	.....	.....	0.20	0.00	0.00	2.13	1.19	0.90	3.28	1.22	1.27	.....
Whitlows.	2,050	.....	.....	.....	.....	0.00	0.06	2.67	1.58	1.68	3.16	1.21	0.91	.....
Silver King.	3,650	2.25	0.35	0.00	0.10	0.00	0.00	4.74	3.03	2.73	3.66	3.40	0.90	21.16

IRRIGATED VINEYARD NEAR PHŒNIX, ARIZONA.

WIND.

The amount and violence of the wind movement is of considerable importance in a climate such as that of Arizona, on account of its effect not only upon the vegetation but also to a certain degree upon the comfort of the inhabitants. A considerable amount of wind is not only injurious to fruit trees, but by continually keeping the dust in motion in such an excessively dry country renders outdoor life extremely annoying to persons who, from lung or throat troubles seek refuge in an arid climate. Fortunately, as indicated by the records and shown by common experience, the wind movement in the Salt and Gila valleys is relatively small, so that the orchards are rarely injured and the amount of dust in the air is not often noticeable. With every disadvantage of this kind there may be a small loss, and in this case the principal drawback is in the fact that windmills can not be used to as great advantage in pumping water as can upon the Great Plains, where the wind has a sweep found nowhere else and prevails throughout the year.

Wind movements have been carefully recorded at a number of places within the Territory, the principal of these within or near the Gila basin being Fort Apache, Fort Grant, Phœnix, Prescott, and Yuma. The record at Phœnix from 1877 to 1891 gives an average hourly wind movement of only 2.4 miles. This small amount is accounted for by the fact that the anemometer was exposed only 15 feet above the ground. As stated by the Chief of the Weather Bureau, in August, 1895, when the station was reestablished, the anemometer was placed 50 feet above the ground, giving considerable higher velocities, the monthly averages being about 5 miles per hour, or more than twice those previously obtained. The averages for Fort Apache were 6.4 miles per hour, for Fort Grant 6.5, for Prescott 6.6, and for Yuma 6.1, all of these being low in consideration of windmill efficiency.

The distribution of wind through the day is very clearly marked. Beginning at about 10 o'clock in the morning, the wind usually increases from about 3 miles per hour up to from 8 to 12 miles per hour at 3 o'clock in the afternoon. At sundown it decreases, dropping off rapidly until midnight, and slowly decreasing in force until about the middle of the forenoon of the next day. Thus, as a rule, nearly all of the effective wind movement occurs within six hours in the afternoon, or from about 1 or 2 o'clock until about sundown. The distribution of wind through the year is comparatively uniform, the greatest amount being in the spring months, the strength decreasing notably during September and October. By erecting tall windmills in well-exposed localities it may be practicable to utilize these to a notable extent in pumping water for irrigation, but to attain success these must be proportioned to the prevailing strength of the wind and to the work to be done. Even if these operate during only

one-fourth of the day, it may be possible, by providing suitable small ponds or earthen tanks, to hold sufficient water for the irrigation of gardens and a small area of forage plants.

PRODUCTS.

It need hardly be stated that on the deep alluvial soil of the valleys in such a climate as that described the growth of nearly all kinds of vegetation is luxuriant if only sufficient water be applied. All warm temperate and many semitropic products flourish here, and most of them produce in an abundance indicated by the favorable climate. The principal crops now grown are alfalfa, wheat, and barley, with more or less of peaches, grapes, apricots, oranges, and other fruits, and a variety of vegetables.

Gila Valley aspires to competition with California in the citrus fruit market, and a number of thriving orange groves indicate that in certain localities the climate and soil are favorable to success. Although there have been many failures, mainly from frost, it should be remembered that this has been the case in every citrus region at first, and that even in California only occasional spots and strips are sufficiently free from frost and other foes of the citrus family to be profitably devoted to this branch of fruit culture. Past experience seems to indicate that, as in California, there are exceptional thermal belts sufficiently exempt from frost to permit profitable growth of oranges and lemons, but such belts can be located only by observation and experience, and their discovery is often preceded by failures due to ignorance or disregard of the true conditions.

There are two respects in which Arizona seems to enjoy a decided advantage over California in the production of citrus fruits: First, the extreme heat and aridity of the climate are claimed to be unfavorable to the development and spread of such enemies of citrus growth as the scale bug (*Aspidiotus perniciosus*) in its several varieties; second, oranges, as well as some deciduous fruits, mature from two to four weeks earlier than in most parts of California, and they thus secure the advantage of an early market, which is always the best. The lemons produced in this valley are beautiful in appearance, of large size, and of excellent flavor. It would appear that this valley is under a disadvantage owing to the inconvenience or expense of curing lemons, which process requires the steady maintenance of a low temperature. The great distance from any sufficiently cool climate and the expense of maintaining local refrigeration seem to stand in the way. Claims are made that the Arizona product does not require curing as in other lemon-growing regions, but this claim seems not yet to be well established. Undoubtedly, however, though lemon culture will be somewhat more restricted than orange culture, it has come to stay. The actual location and development of favorable localities along the lines mentioned will be slow, but enough is known to guarantee the fact

FIG TREE NEAR PHŒNIX, ARIZONA

that if citrus culture continues as profitable as it has been in the past, Arizona will some day be one of the important competitors for a share of the citrus market.

This valley appears to be preeminently the home of the grape. Table grapes of good quality and wine grapes yielding a very superior product may be grown here in abundance, as already proved by experience. Undoubtedly, also, the raisin industry will some day be important, and the hot, dry summers are favorable to the production of a superior article. In one respect, however, this valley is under a disadvantage as compared with southern California, in that it is more likely to receive sudden showers of rain during the curing season.

Claims are also made of the superiority of this region for such products as figs, prunes, almonds, pomegranates, olives, and even dates. Undoubtedly figs and prunes can be successfully grown, and the experience obtained with almonds both in this and other localities seems to justify the claims made regarding this product, but most of the other fruits mentioned are still in the experimental stages. It is doubtful if dates can be profitably grown except in some favored and well-sheltered localities. Apples appear not to do well in a climate like that of Arizona. Even those varieties which can be abundantly grown are inferior in quality and quickly decay. This fruit is better adapted to a colder climate. The same appears to be true in a less degree of pears. Most small fruits yield abundantly, and so far have been very profitable.

The quantities of fruits and vegetables which have been exported from Arizona are inconsiderable. On the contrary, large quantities of some kinds are annually imported for consumption in the industries of mining and grazing. These two interests are the main sources of exportable products, and agriculture and horticulture, so far as developed, are devoted chiefly to satisfying their wants. Alfalfa may be taken as the staple agricultural product, and is largely utilized in the fattening of cattle grown on the ranges of the adjacent mountains and foothills. Large areas of this productive forage plant are used as pasture, while others are utilized for maturing hay. Barley is largely used as hay, and also furnishes the bulk of the grain fed to live stock in the valley.

METHODS OF APPLYING WATER.

Alfalfa and the grains being the principal crops of this region, it may readily be inferred that the usual method of applying water in irrigation is by flooding the ground, since these products lend themselves to this method most readily. This system, as is well known, is also susceptible of great wastefulness in its application, especially in an ultra-arid climate, since it wets the whole surface of the ground and gives full scope to evaporation, and is often followed by baking, which favors the rise of underground waters to the surface to evaporate.

In the irrigation of fruit trees and vines the furrow method is used, which, when properly employed, is an excellent method. Pl. VII shows the ground properly prepared for the furrow method of irrigation. The water is turned into each furrow at the upper edge of the field in just sufficient quantity to run freely down the furrow without erosion, and soaks gradually away downward and sidewise. As soon as it reaches the lower end of the furrow it is shut off at the upper end; thus only a small percentage of the surface of the ground is wet, and the water reaches the roots of the trees at some distance below the surface. A light cultivator should follow irrigation, filling the furrows with loose earth and leaving the surface of the ground level

FIG. 2.—Irrigation by flooding

and dry, so that the minimum of evaporation takes place and no saturated surface is exposed to bake in the hot sun. Unfortunately, however, the predominance of the flooding system seems to influence irrigation by means of furrows, and the water is often so lavishly and carelessly applied that the ground is almost flooded, and the water stands in pools and furrows until the field becomes an absolute bog, a condition which is not only most wasteful of water, but actually injurious to the irrigated corps, by shutting off the ventilation of the roots. It also interferes with cultivation, causes the ground to bake, and allows the weeds to start. This is, however, by no means the universal practice, and many of the irrigators are approaching more and more nearly to ideal methods of irrigating. The Arizona Improve-

PALM AVENUE NEAR PHŒNIX, ARIZONA.

ment Company is setting an excellent example in this respect, as are also some of the individual irrigators, and the neat appearance of the orchards might profitably be emulated by many a city park.

WATER SUPPLY.

In comparison with the size of the Territory and the importance of its water resources, the hydrographic data are very meager. Some measurements of stream flow were made in 1889 and 1890 by the United States Irrigation Survey at a point about 14 miles above Florence, on the Gila River, known as The Buttes. Gaugings at this point were resumed in December, 1895, and are still being carried on, the

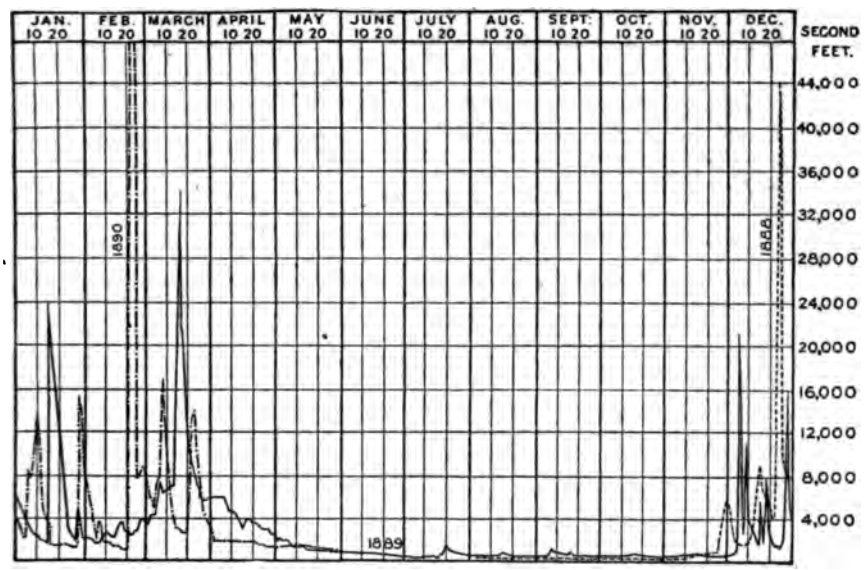


FIG. 3.—Daily discharge of Salt River at Arizona dam, 1888–1891.

results being used also to estimate the discharge from gauge readings and soundings taken during the fall of 1895 by private parties. Measurements have also been made by the United States Government of the discharge of Queen Creek, a small intermittent stream tributary to the Gila River.

Approximate estimates of the discharge of Salt River were made by Mr. Samuel Davidson from data obtained by the Arizona Cana- Company at its dam a short distance below the junction of the Salt and Verde rivers.

Measurements of discharge have been more recently made on Salt and Verde rivers by the Hudson Reservoir and Canal Company. Surface velocities were measured by means of floats, and eight-tenths of the result thus obtained was assumed as the mean velocity, and mul-

tiplied into the cross section determined by sounding, to obtain th discharge, the sum of the discharges of both being adopted as the flo of Salt River below the junction. The measurements were begun o February 4, 1895, and were continued through the year without inte ruption except on the four days from October 4 to 7, inclusive, o Verde River, which was during that time inaccessible. An estima for those four days has been made from the highest watermark foun at the gauge and from such other data as were available. Also, for th month of January, one of the most important flood months of the yea estimates have been prepared from the daily record taken at the Ar zona dam, about a mile below the junction of the two rivers. It appea from all available data that Salt River furnishes a considerably larg proportion of water than Verde River, and the assumption has bee made that 60 per cent of the January flow at the Arizona dam can from Salt River above the Verde.

VIEW ON BARTLETT RANCH, NEAR PHŒNIX, ARIZONA.

ıe results of the computed discharges for each locality are given ıe following tables:

Estimated monthly discharge of Salt River at Arizona dam, Arizona.

[Drainage area, 12,260 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1888.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
August	.....	.....	350	21,525	0.03	0.028
September	.....	.....	350	20,825	0.03	0.028
October	350	300	331	20,356	0.03	0.027
November	5,760	425	842	50,099	0.08	0.068
December	43,489	1,665	6,698	411,927	0.63	0.545
1889.						
January	24,953	1,665	5,947	365,740	0.56	0.48
February	3,940	1,534	2,605	144,577	0.22	0.22
March	33,794	3,563	8,745	537,817	0.82	0.71
April	5,559	2,496	3,975	236,512	0.36	0.32
May	1,784	622	1,039	63,898	0.10	0.08
June	615	356	470	27,965	0.04	0.04
July	1,311	334	495	30,522	0.05	0.04
August	755	389	417	25,645	0.04	0.03
September	1,172	389	521	31,000	0.05	0.04
October	704	319	440	27,060	0.04	0.04
November	629	532	576	34,272	0.05	0.05
December	25,371	557	5,686	349,689	0.53	0.46
1890.						
January	15,750	1,376	4,982	306,393	0.47	0.40
February	143,288	1,045	10,097	560,383	0.86	0.82
March	17,228	2,596	6,421	394,891	0.60	0.52
April	2,077	1,369	1,840	109,480	0.17	0.15
May	1,369	630	914	56,211	0.09	0.08
June	672	397	511	30,404	0.05	0.04
July	872	397	524	32,226	0.05	0.04
August	7,734	1,114	3,885	238,927	0.37	0.32
September	3,685	725	2,339	139,170	0.21	0.19
October	7,465	753	2,768	160,232	0.25	0.23
November	30,504	766	4,717	280,661	0.43	0.38
December	30,366	1,110	6,259	384,928	0.59	0.51
1891.						
January	17,127	1,060	3,416	210,084	0.32	0.28
February	300,000	825	39,201	2,175,655	3.32	3.10

Estimated discharge of Verde River above Salt River, Arizona.

[Drainage area, 6,000 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1895.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
January	33,000	527	4,037	248,225	0.77	0.67
February	5,800	583	1,688	93,747	0.29	0.28
March	8,400	1,887	3,720	228,734	0.71	0.62
April	2,800	280	750	44,628	0.14	0.13
May	429	127	258	15,864	0.04	0.04
June	180	129	153	9,104	0.03	0.03
July	275	116	145	8,916	0.02	0.02
August	1,426	185	359	22,074	0.07	0.06
September	348	141	176	10,473	0.03	0.03
October	3,912	197	475	29,207	0.09	0.08
November	1,800	241	463	27,550	0.09	0.08
December	881	345	391	24,042	0.08	0.07
Total, year	33,000	116	1,051	762,564	2.38	0.18
1896.						
January	354	314	324	19,923	0.06	0.05
February	352	278	154	8,852	0.03	0.03
March	338	258	276	16,971	0.06	0.05
April	237	206	220	13,090	0.04	0.04
May	206	138	172	10,576	0.03	0.03
June	137	101	117	6,962	0.02	0.02
July	3,380	98	864	53,127	0.16	0.14

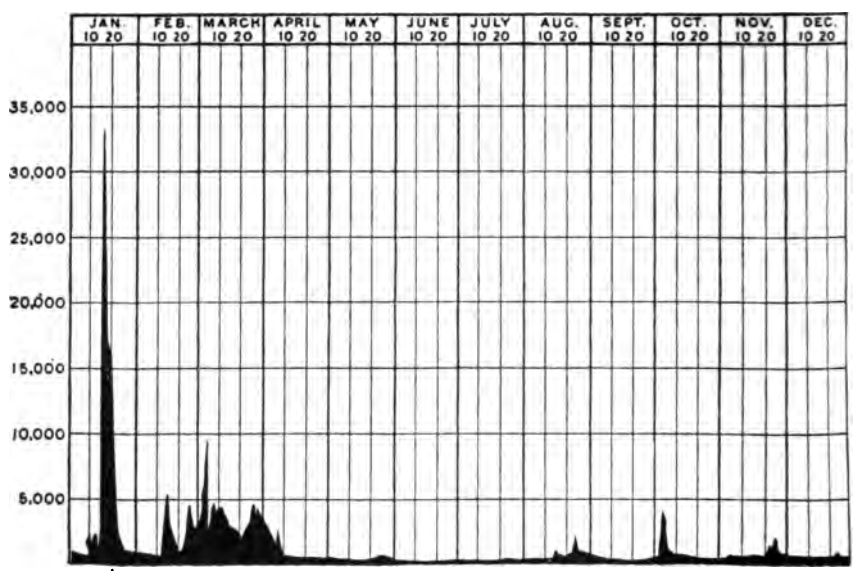


FIG. 4.—Daily discharge of Rio Verde above Salt River, 1895.

DRYING APRICOTS.

Estimated discharge of Salt River above mouth of Verde River, Arizona.

[Drainage area, 6,260 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1895.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
January	49,796	791	5,733	352,508	1.06	0.92
February	3,892	914	1,445	80,251	0.24	0.23
March	3,340	1,319	1,829	112,461	0.33	0.29
April	2,939	1,044	1,860	110,678	0.33	0.30
May	990	505	708	43,533	0.13	0.11
June	500	203	325	19,339	0.06	0.05
July	896	145	204	12,543	0.03	0.03
August	1,516	226	584	35,909	0.10	0.09
September	684	201	329	19,577	0.06	0.05
October	13,205	390	1,624	99,856	0.30	0.26
November	9,620	380	1,376	81,878	0.25	0.22
December	2,055	513	888	54,601	0.16	0.14
Total, year	49,796	145	1,408	1,023,134	3.05	0.22
1896.						
January	613	400	470	28,900	0.08	0.07
February	612	414	476	27,380	0.09	0.08
March	3,020	457	1,185	72,863	0.22	0.19
April	1,660	605	959	57,061	0.17	0.15
May	621	335	446	27,424	0.08	0.07
June	332	158	224	13,328	0.04	0.04
July	4,377	151	639	39,292	0.12	0.10

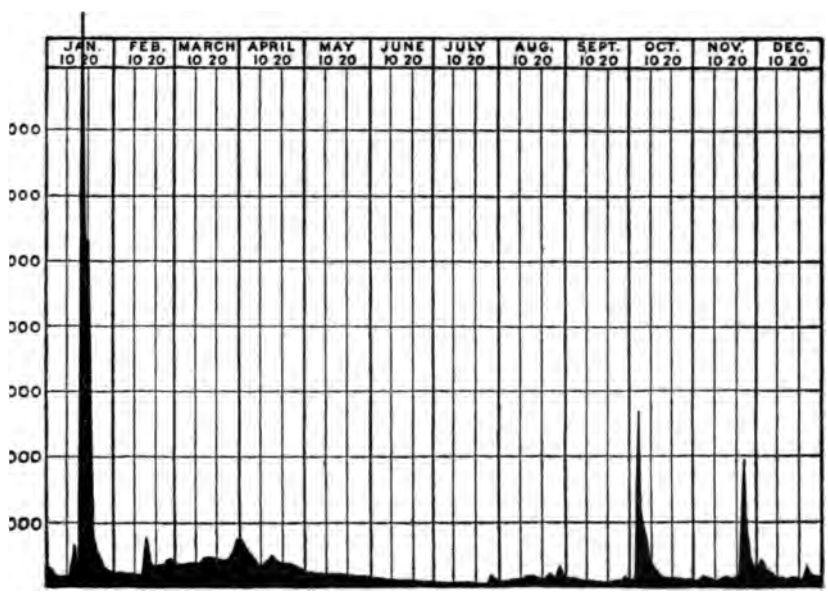


FIG. 5.—Daily discharge of Salt River above Verde, 1895.

The following table shows the discharge of Gila River for the seas of 1889–90, measured by the irrigation survey, and the results fr measurements still in progress for the season just closed:

Estimated discharge of Gila River at The Buttes, Arizona.

[Drainage area, 13,750 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1889.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
September	210	90	128	7,616	0.010	0.009
October	210	140	157	9,655	0.013	0.011
November	250	156	212	12,614	0.017	0.015
December	890	124	275	16,909	0.023	0.020
1890.						
January	2,100	310	680	41,812	0.056	0.049
February	1,514	405	578	32,100	0.043	0.042
March	710	300	387	23,795	0.032	0.028
April	333	158	238	14,161	0.019	0.017
May	150	35	87	5,350	0.007	0.006
June	35	27	28	1,666	0.002	0.002
July	3,112	11	130	7,995	0.010	0.009
August	6,330	1,115	3,137	192,888	0.263	0.228
Total, year				366,561		
1895.						
August	3,910	536	1,583	97,336	0.133	0.115
September	2,880	300	812	48,317	0.065	0.059
October	12,000	400	1,577	96,966	0.133	0.115
November	7,500	300	1,103	65,633	0.089	0.080
December	1,150	518	751	41,627	0.056	0.049
1896.						
January	560	250	396	24,349	0.032	0.028
February	340	175	209	12,022	0.016	0.015
March	356	153	242	14,880	0.021	0.018
April	340	68	180	10,710	0.014	0.013
May	68	12	32	1,968	0.002	0.002
June	32	1	5	298	0.0003	0.003
July	11,708	1	1,441	88,604	0.121	0.105
August	3,150	175	810	49,805	0.068	0.059
September	2,850	455	980	58,314	0.079	0.071
October	7,243	1,030	4,145	254,867	0.347	0.301
November	2,275	696	1,037	61,706	0.083	0.075
December	710	576	629	38,676	0.053	0.046
Total, 1896.	11,708	1	842	616,201	0.839	0.062

In the above table the discharge for the period from August 1 December 10, 1895, is estimated from observations of mean depth a width made by Mr. W. Richins, and can be considered only as a rou approximation.

IRRIGATION BY FURROW METHOD.

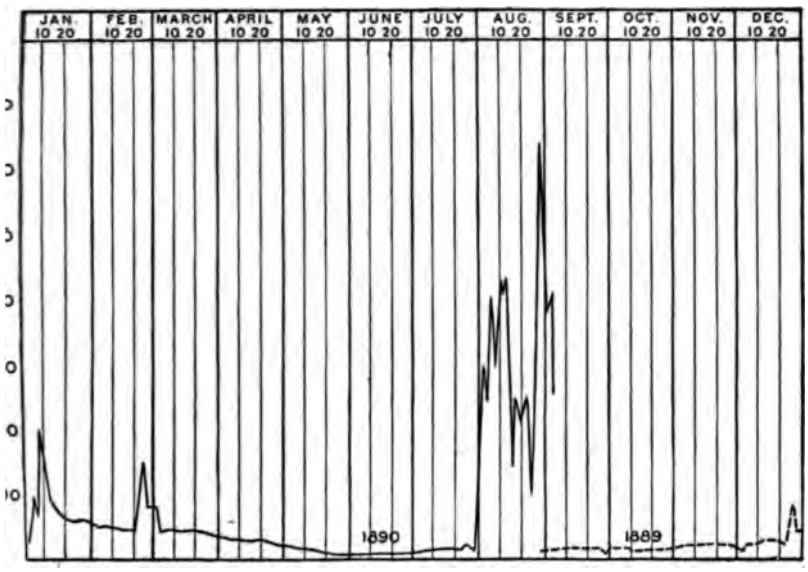


FIG. 6.—Daily discharge of Gila River at The Buttes, 1889-1890.

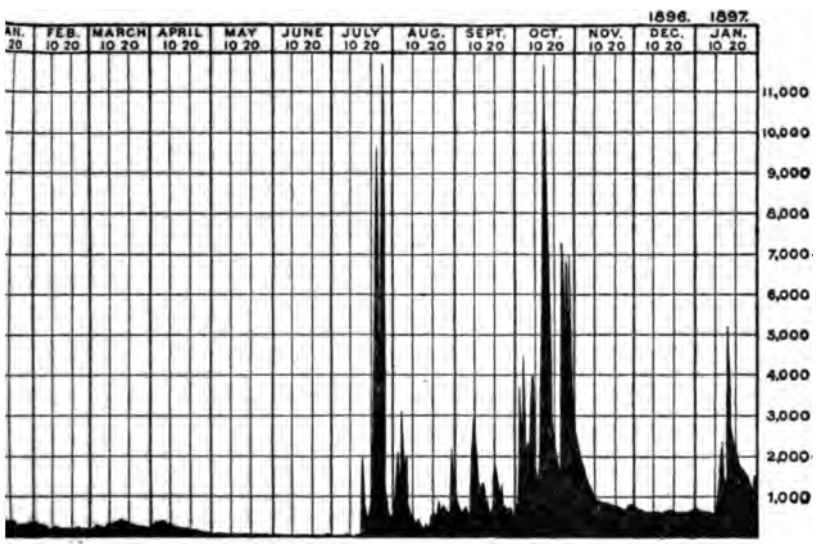


FIG. 7.—Daily discharge of Gila River at The Buttes, 1896.

Estimated monthly discharge of Queen Creek, Whitlows, Arizona.

[Drainage area, 143 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1896.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
January	2	2.0	2.0	123	0.016	0.014
February	2	2.0	2.0	115	0.015	0.014
March	2	2.0	2.0	123	0.016	0.014
April	2	1.0	1.5	87	0.011	0.010
May	1	1.0	1.0	61	0.008	0.007
June	1	1.0	1.0	60	0.008	0.007
July	9,000	0.0	121.6	7,480	0.980	0.850
August	1,433	0.6	13.1	805	0.106	0.092
September	3,428	0.5	17.1	1,016	0.134	0.120
October	1,188	0.5	13.3	820	0.108	0.093
November	80	0.6	1.3	80	0.010	0.009
December	207	0.6	2.0	120	0.016	0.014
Total, year	9.000	0.0	15.0	10,890	1.428	0.104

DUTY OF WATER.

The actual attained duty of water in Salt River Valley was approximately determined in the year 1895. According to figures furnished by the Arizona Improvement Company, about 60.000 acres were irri-

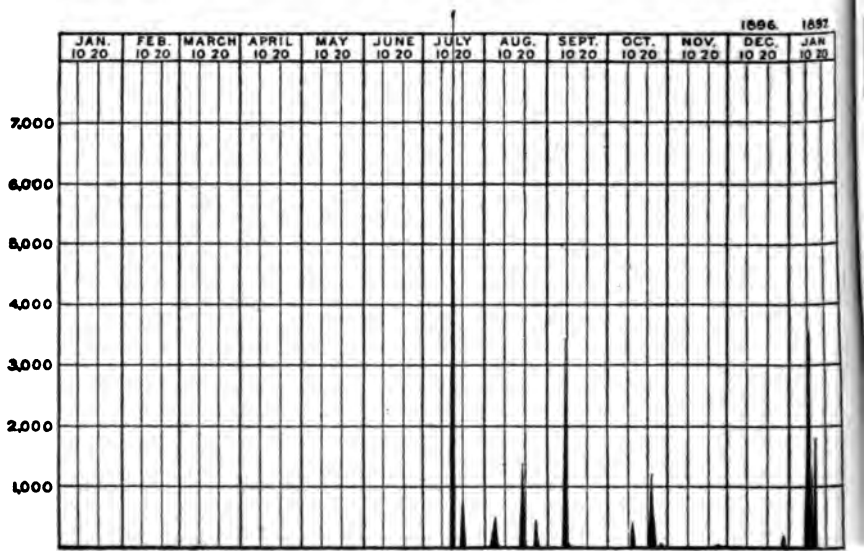


FIG. 8.—Daily discharge of Queen Creek.

gated on the north side of Salt River in that year. Of this, about 34,000 acres, or more than one-half, was in alfalfa; over one-fourth was in grain, and the remaining portion, or about one-sixth, was chiefly in fruit and garden or was occupied by streets and lots of

FIELD PREPARED FOR IRRIGATION BY CHECKS.

DRYING APRICOTS.

SILT AND ALKALI.

As indicated by its name, Salt River carries a notable quantity of mineral matter in solution. It becomes an interesting question, therefore, whether its use in irrigation will eventually lead to deterioration of the soil through the deposit of alkaline salts. Over most of the valley no such injurious effects are noticeable. This may be due partly to the excess of water applied, which, escaping to the subsoil, carries the salts in solution and bears them away through the gravels to the river bed; and accordingly it is found that where the fields are underlain at a reasonable depth by beds of gravel no accumulation of salts is noticeable, while in the vicinity of Tempe, where the subsoil is practically impervious, and where the ground water is near the surface, considerable tracts of land are to be seen impregnated with alkali, some of it to such an extent as to be of little use in its present condition except for grazing. Inquiry among the inhabitants leads to the conclusion that, although such alkaline indications were noticeable before irrigation became extensive in this valley, these areas have been greatly increased since that time, either from the rise of alkali from the subsoil or from its deposit upon the land by the irrigating waters, for which adequate drainage was not provided. Some tracts of land have even been abandoned from this cause.

It has been stated that a great excess of water is applied in this valley for irrigation and that the progress of methods of economy and the storage of surplus waters in the mountains will undoubtedly lead to a much more sparing application. The question naturally arises, therefore, whether, when the abundant leaching which is provided by the seepage downward of the excess waters is discontinued, the fields in the vicinity of Phœnix and Mesa will not become impregnated with salts to an injurious extent. Any such fear seems to be entirely unfounded. The whole valley, with the exception of the area in the vicinity of Tempe above mentioned, seems to be so thoroughly underlaid with coarse gravel that it will be entirely practicable at any time to leach out the salts by the application of a large quantity of irrigating water for that purpose. At intervals of several years, also, there occur heavy rainfalls in these valleys, which, from their sudden nature and long intervals, can not be depended upon for assistance in agriculture, but which will always be of value for leaching the soil in the manner above referred to.

MIDDLE GILA VALLEY.

There are several ditches built to divert water from the Gila River in Pinal County, but they have all been practically abandoned except the Florence Canal, on the south side, and the McClellan and Arthur ditches, on the north side of the river. This is due to the shortage of water in recent years, caused probably by increased

GILA BEND DAM, LOOKING EAST.

IRRIGATION BY FURROW METHOD.

GILA BEND DAM, SPILLWAY AND HEADWORKS.

e Southern Pacific Railroad at the town of Gila Bend being given
7 feet, and of Yuma, at the mouth of Gila River, 40 feet. Both
ese towns are considerably above the level of the bottom lands.
nsequence of its low elevation the temperature is extremely high,
were it not for the aridity of the climate the summer heat would
most unbearable. The lands along the river are of great fertility,
where watered produce abundant crops. The Southern Pacific
road extends in a general way parallel to the river and from 2 to
iles away, except above Gila Bend, where the river describes a
t loop. The irrigating systems are, on the north side, the Buck-
and Monarch canals, and on the south side of the river Rumberg's
l, Gila Bend Canal, and Upper Gila or Palmer Canal. Farther
l, below Gila Bend, are a number of other systems, lying beyond
imits of the area described in this paper.

BUCKEYE CANAL.

ıe Buckeye Canal was begun in 1885, and water was first used in
. It heads on the north side of Gila River, about 4 miles below
unction of Salt River, and just below the mouth of the Agua Fria.
ownership is divided into shares, each of these representing 80
r's inches. It is about 25 miles in length, and is built on a grade
feet to the mile. At the head it is 19 feet wide, and has a depth
out 3 feet, and a capacity of about 75 cubic feet per second. It
22 small laterals, and the main canal of course decreases in size
.e laterals are taken out.

GILA BEND CANAL.

ıe dam of the Gila Bend Reservoir and Irrigation Company (Pl. IX)
cated about 40 miles southwesterly from Phœnix and 25 miles
l of the Gila Bend Station, on the Southern Pacific Railroad. It
arly 2,400 feet long, and as originally planned was to be an over-
weir built of timbered cribs loaded with rock and anchored to
driven in the bed of the river. After the completion of about 600
of the east end the expense involved induced the company to alter
lans and to build the remaining portion of loose rock, the part
dy constructed being intended as a waste weir, and the rock por-
was built about 6 feet higher (Pl. X). The top width of the rock
on was about 18 feet, and the side slopes 1½ to 1. From the first,
us doubts of the stability of the dam were entertained by those com-
ıt to judge. It was generally conceded that the first water which
opped the loose rock portion of the dam would wash it out. In
of this fact, and the published records of the discharge of the
showing floods approximating 300,000 cubic feet per second, it
natter of surprise that the capacity of the waste weir was left at
about 30,000 cubic feet per second.

e first indication of a failure was in January, 1893, when a slight
n the river caused the loose rock portion of the dam to settle

several feet. This portion was raised to its original height, an dam was declared completed, at a cost of nearly $200,000. In J of the same year a heavy flood washed out 500 feet of the dan the center. This breach was repaired, and in October of the year, when the river rose again, 400 feet at the west end of th went out. It was now decided to make the dam a waste weir ex ing entirely across the river, and plans were drawn up and oper begun accordingly. The original wooden portion of the dan thoroughly overhauled and all warped or defective timbers were out and replaced by new ones, and the crest of the weir was rais feet. In the portion built originally of loose rock several ro piling were driven from 13 to 18 feet into the bed of the river. were cut off and framed over with heavy 10-inch by 12-inch tin The crest of the new portion stood 2½ feet above the raised crest old weir. The new design also called for sheet piling above and the dam for its entire length and a row of detached cribs belo aprons on the lower side. In January, 1895, before the new wor completed, another freshet ran about 8 feet deep over the entire l of the dam, discharging nearly 180,000 cubic feet per second washing out the uncompleted portion of the dam for about 40 from the west end, which has not been replaced. The prope this company is in litigation, and further repairs and develo must await settlement of legal questions.

The canal was begun in May, 1892, and completed the foll year. Its total length is 38 miles, with varying bottom widths, ents, and depths, as shown in the following table:

Dimensions of the Gila Bend Canal.

Length.	Gradients per mile.	Bottom width.	Depth.
Miles.	*Feet.*	*Feet.*	*Feet.*
½	0.5	30	10
5½	0.5	25	10
6	0.5	24	10
6	0.5	23	10
6	0.5	22	10
7	0.6	20	10
4	0.7	15	9½
3	0.8	10	9

The side slopes were 1:1 in cut and 1½:1 in fill. The level s of the canal was a cut of 4½ feet, with embankments of 5½ f either side, with berms of 2½ feet. Nine flumes, aggregating 4 in length, were substantially built of wood. Twenty-one sing 2 double culverts, consisting of 24-inch cement pipe and aggre 2,705 feet, were inserted. About 75 miles of laterals have bee

GILA BEND CANAL HEADGATES.

tructed. The head-gates are large iron structures between massive asonry abutments and wing walls. (See Pl. XI.) The head-gate nd canal may be taken as one of the best and most substantial works f the kind yet constructed. The entire project is reported to have ost about $1,000,000.

About 10 miles below the Gila Bend Reservoir and Irrigation Com- any's dam the lower Gila Bend Canal heads, on the same side of he river, and covers a narrow strip of land about 15 miles in length. t is 11 feet wide, and is said to have cost about $25,000. It was first sed in 1885. Water is diverted by means of a temporary dam of rush and stone, which is renewed when required. It is a cooperative concern, owned by the irrigators in the form of 36 shares, each ntitling the holder to a proportionate part of the water.

SALT RIVER VALLEY.

As previously defined, Salt River Valley is taken as including the ands adjacent to Salt River extending from the mouth of its principal ributary, the Verde, down to the point where Salt River empties into ila River, a distance in a direct line of about 40 miles. The fall of he river between these points is so great that water can be readily iverted at almost any part of the river's course and carried diago- nally away from the stream, covering in the course of a few miles a considerable extent of country. As shown by the map (Pl. XXX), canals have been constructed heading at short intervals from near the upper end of the valley down along its whole course. The principal of these canals are shown in the following list, which gives also the approximate length and the year when first used. These canals have n aggregate of nearly 600 miles of lateral ditches.

Principal canals of Salt River Valley.

Name	Source	When first used
NORTH SIDE.	Miles.	
Arizona		
Grand		
Maricopa		
Salt River Valley		
Farmers		
St. John		
SOUTH SIDE.		
Highland		
Consolidated		
Old Mesa		
Tempe		
San Francisco		

The following description gives the principal facts obtainable concerning these canals, the descriptions being arranged in geographic order, first those on the north side and then those on the south.

ARIZONA AND OTHER NORTH-SIDE CANALS.

The Arizona Canal, constructed in the years 1883 and 1884, heads highest on the river and has the only permanent dam. This dam, or weir, is located about 1 mile below the mouth of the Verde, and extends diagonally across the river in a northeasterly direction from a rock projecting into the stream from the right bank to a rock on the left bank. At the time of its construction the river channel was against the right bank, and on the left side a gravel bar sloping from the channel to the bank extended to a depth of 8 or 10 feet. This bar was excavated to the surface of low water for a width of 60 feet, and the dam was begun with mudsills 8 inches by 10 inches by 48 feet, laid parallel with the stream at intervals of 10 feet. Upon the upstream half of these sills is built a continuous crib with cross-ties every 10 feet, into which the rails are gained, a space of 4 inches being left between the rails, which are fastened with 12-inch drift bolts three-fourths inch in diameter. The front and back sides of the crib have a batter of one-fourth to one, and are covered with 2-inch plank with 6-inch sheet piling drifting at its back. The rail is laid lengthwise on mudsills in the center of the crib, and constitutes the only floor of the crib, which is filled with bowlders.

The crest of the dam for a distance of 416 feet on the left bank is 10 feet above low water and is covered with 3-inch plank, spiked to the rails and braced and propped from cross-ties below, and having a slope of 3 feet upstream. Rails are laid upon the mudsills projecting 24 feet downstream, 4 feet apart, and covered with 3-inch plank for apron, and sheet piling 3 inches thick and 18 feet in length driven at lower edge of apron. Below the apron the gravel was excavated and cribs put in 4 feet deep and 12 feet wide, of various lengths from 10 to 24 feet, with double rods to bind corners. These cribs were filled with rock and covered with 3-inch plank. The portion of the dam just described is still standing. The part built across the channel was constructed similarly, and went out in the great flood of 1891 and was replaced by a more substantial structure, having the overfall broken into a series of steps, and the 5-foot sections of dam bound together with 1¼-inch iron rods from top to bottom. Sheet piling was driven at both the heel and toe of the renewed portion. The current strikes the crest of the dam at an angle of about 12°. Between the southwest end of the dam and the canal head-gates a wasteway was blasted out of the rock 36 feet in length, and prepared to receive slash boards, which can be easily removed when necessary to draw off the water from the back of the dam during low water for repairs. The total distance at high water over the dam wasteway and rock on level with dam is 1,000 feet.

VIEW OF ORIGINAL ARIZONA DAM.

GREAT FLOOD OF 1890 ON SALT RIVER.

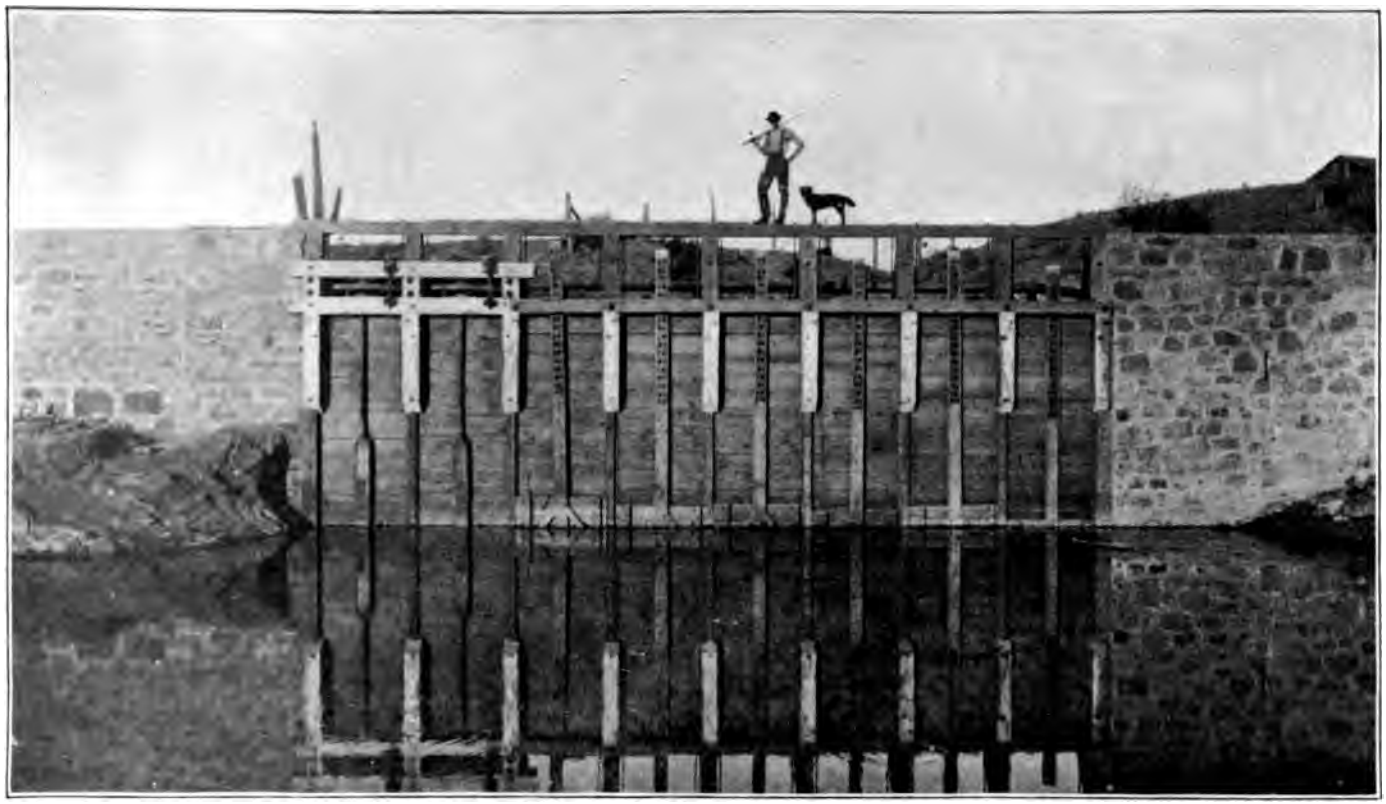
he head works of the canal are in solid rock, with masonry abut-
ts and wing walls and wooden gates. The bottom width of the
l is 36 feet at the head, and becomes narrower toward the lower
The estimated capacity is 1,000 cubic feet per second. For the
3 or 4 miles there is considerable heavy construction, the country
g somewhat rough, and the material to be moved consisting
ely of gravel, with some solid rock. The canal was first used in
. It is 47 miles long, and cost $600,000.
rand Canal, heading about 2½ miles above the consolidated head of
Salt River Valley and Maricopa canals, was constructed in 1878.
capacity of this canal is 215 second-feet. It has been absorbed
he Arizona Canal Company, its head works have been abandoned,
it receives water from the Arizona Canal through what is called
Crosscut Canal. This latter was constructed in 1889, partly for
purpose of economizing the water to which the Grand Canal is
tled by carrying it through the Arizona Canal instead of through
sandy bed of the river, and partly to utilize for power purposes
fall between the Arizona and Grand canals. Its capacity is about
second-feet, and it supplies water for the Grand Canal, and at
s during low water for the Salt River Valley and Maricopa canals.
he oldest diversion from Salt River for irrigation purposes is the
River Valley Canal, constructed in 1867 by Jack Swilling and his
ciates, and called originally the Swilling Ditch. It is on the north
of the river, about 5 miles east of Phœnix. Some time after its
struction another canal or branch was taken from it, at a point
it 3 miles below its head, which became known as the Maricopa
al. These two canals with a common head are sometimes called
Consolidated Canals. The diversion is by means of an artificial
l formed of rocks and brush through wooden head-gates, with
l masonry abutments and wing walls. The capacity of Salt River
ley and Maricopa canals jointly is about 275 second-feet. Both
ls are now controlled by the Arizona Canal Company.

SOUTH-SIDE CANALS.

he Highland Canal was built early in 1889. It takes water on the
h side of the river, about 2 miles below the head of the Arizona
al, and has a capacity of about 100 cubic feet per second.
he Mesa City Canal was begun in 1879 by the Mesa Canal Com-
y, a corporation composed of the owners of the land to be watered
he canal. It emerges from the river on the south side, about 2½
s above the head of the Utah Canal, being above the head of all
canals and ditches previously constructed. It supplies water to
a City and adjoining country, and has a capacity of about 175
nd-feet. Its alignment for a considerable distance is said to have
owed the line of one of the prehistoric canals of this valley. One
re of stock in this canal represents a maximum of 17½ miner's

inches, or a little over two-fifths of a cubic foot per second. The water represented by a share supplies about 40 acres of land and is valued at present at about $250. The annual charge per share is $14. Considerable expense and annoyance was experienced for many years from the insecure head works of this canal, the farmers frequently being obliged to quit work in the busy season to restore their supply of irrigating water. Finally, in 1893, the Consolidated Canal Company was formed, which entered into a contract to build new head works and to deliver a specific quantity of water for a consideration at a designated point on the Mesa Canal for the use of the owners of that canal. This company built a shoal of large bowlders across the river, which withstands the floods of the river, but it gradually settled, at first into the sand and gravel of the river bed. As settlement proceeded it has been built up and constitutes a very fair means of diversion. At the south end of this shoal are built massive granite masonry abutments and wing walls, between which the canal flows through wooden gates directly into the mesa of bowlders and hardpan, through which it is constructed in a deep cut for a distance of over 2 miles, the maximum cut being about 26 feet. This heavy construction was performed by a huge dredge with a dipper capacity of 2 cubic yards of earth and having a lift of 26 feet. At the end of these 2 miles the Consolidated Canal follows for some distance the alignment of the Mesa Canal until it reaches a point about 3 miles northeast of Mesa City, which is designated as the point of delivery of the specific quantity of water for the irrigators under the Mesa Canal. At this point the water for the Mesa Canal Company is discharged into their old canal, and two branches are constructed by the Consolidated Canal Company, one starting southeast for irrigating purposes, and one running due west for about 2 miles until it reaches the edge of the mesa, just above the Tempe Canal, where a large power plant is constructed for electric lighting and power purposes, using the irrigating water to which the Tempe Canal is entitled and discharging it from the wheels into the Tempe Canal about 1½ miles below its head. For some time the right to use the irrigating waters of the Tempe Canal was questioned, but this matter is now said to be adjusted. The eastern branch of the Consolidated Canal above mentioned is constructed on a light-grade line, in a general southerly direction, to the boundary of the Gila River Indian Reservation. By carrying the water of the Tempe Canal through the Consolidated Canal instead of through the sandy river bed, a considerable loss by evaporation is prevented, and the water available for irrigation is thereby increased. In this manner the Consolidated Canal obtains a right to some irrigation waters.

The Utah Canal was constructed in 1877 on the south side of the river, heading about 5 miles above the head of the Tempe Canal. It was constructed and is operated by the owners and occupants of the



ARIZONA CANAL HEADGATES.

VIEW OF PRESENT ARIZONA DAM.

nds which are irrigated by its waters, and the association is unin-
rporated, the water rights being represented by certificates which
e transferable. Its capacity is about 175 second-feet.

In 1870 a ditch was constructed on the south side of the river,
own as the Tempe Irrigating Canal. It heads about 7 miles above
e Salt River Valley Canal, and was carrying in June, 1896, about
4 cubic feet of water per second. This is a community ditch, the
operty of the owners of the land irrigated from it, the shareholders
ing unincorporated. The canal has a carrying capacity of 337
bic feet of water per second.

The San Francisco Canal, known also as the Wormser Canal, was
nstructed on the south side of the river in 1875. It heads a short
stance below the town of Tempe, and has a capacity of about 52
econd-feet.

Mr. C. T. Hayden, a shareholder of the Tempe Canal Company, in
e year 1874 erected a flouring mill at Tempe, and by an arrange-
nt with the other shareholders obtained a supply of 27½ cubic feet
water per second to run his mill.

AREA IRRIGATED.

It is extremely difficult to obtain reliable figures concerning the
ea irrigated in any locality. This is true in the Salt River Valley
elsewhere, and is due not only to the fact that farmers as a rule do
t keep records of the results of their labors, but also because of the
ny influences tending toward exaggeration of statements. It is
ually to the interest of the farmer as well as the canal owner to
aim that a large area is irrigated, so that in case of subsequent con-
oversies over water rights his title to the use of water may be sup-
rted. The matter of definition also, as to what may be considered
irrigated, introduces complications. In order to secure title under
e desert act, claims are made and proofs submitted that hundreds
acres are irrigated, although as a matter of fact this irrigation is
the most nominal character, and to the eye the land has received
apparent benefit.

A systematic attempt was made by the Eleventh Census to obtain
exact statement as to the amount of land actually irrigated and
opped in the census year 1889. A farm-to-farm enumeration was
ade for the purpose of obtaining the area of land in each farm, the
nount improved, cultivated, and irrigated, the area and quantity of
ops, and many other details. It was found during this census that
aims were frequently made that 160 acres were irrigated, when the
ops aggregated only about 30 or 40 acres. Examination revealed
at as a rule the amount claimed as irrigated represented the amount
land under ditch and to which water might perhaps be taken,
hile actually, either from deficiency of water or other cause, success-
l irrigation was conducted only upon the smaller area.

The total area irrigated in Arizona and from which crop obtained during the season of 1889, according to the Eleventh C was only 65,821 acres, the greater part of this being in barley, a and other forage crops. Of this amount, the area irrigated in copa County was found to be 35,212 acres. A large portion was on the south side of Salt River. For comparison, and to illu the difference obtained by estimates based upon the claims of owners and farmers, it is stated that on the north side of Salt in Maricopa County, there were irrigated in 1889, under the A Canal, 56,000 acres. This amount, or 350 quarter sections, quantity given in the decision noted later on page 61. Th given as irrigated from the Arizona Canal system in 1895 was 60,000 acres. The discrepancy between the census figures a amount adjudicated may be due to a number of causes, but is ably accounted for largely by the fact that many of the tracts to water rights were adjudicated were cultivated only in part, a not yield crops of sufficient size to be reported by the owners e merators. Many of the tracts formerly claimed as irrigated hav the acquisition of title been left uncultivated. It is suggestive in this connection that the adjudicated rights of some of the canals aggregate more than their entire capacity.

The first irrigation under the Arizona Canal occurred in 1885 decision handed down by Judge Kibbey (page 61) adjudicated for the year 1884 aggregating 82,600 acres. On the basis of th of water assumed by the court—100 acres per second-foot—it require for the satisfaction of these rights a flow of 826 cubic f second. By reference to the table of discharges of Salt Ri Arizona dam, on page 37, it is seen that the mean flow for the of July in 1889 was 495 second-feet, and for the same month in was 524 second-feet. The flow for the month of June, which it be safe to assume as available for irrigation, would be not mor 500 cubic feet per second, whereas in the year 1884, as just b before the Arizona Canal was brought into use, 826 second-fee required to satisfy the legal rights existing in the valley. But of grain can be matured in this valley by the growth in the wint spring, and large areas are undoubtedly matured every year the 1st of June. The minimum flow for the month of May, ho is given as 622 second-feet in 1889, and as 630 second-feet in while the mean for the entire month in 1890 is 914 second-feet.

The two minima given would seem to indicate that a shorta imminent even in the month of May in 1884, if the rights as e cated were all claimed. If this was the case in 1884, what can of 1889, when instead of 82,600 acres claiming water there hav adjudicated rights amounting to 151,360 acres? The areas tha been irrigated since 1889 under the Arizona Canal system have ably been increased, so that the total area using or claiming

FALLS ON ARIZONA CANAL

VIEW ON CROSSCUT CANAL

om Salt River is double what it was in 1884, and consequently more
an double the capacity of the river to supply in ordinary years, and
ill more beyond its capacity in dry years. But the condition of
rigation in Salt River Valley is not as bad as these figures would
em to imply. As above indicated, the adjudicated rights are prob-
ly greater than the areas actually irrigated in the years given, and
ltivation has been discontinued on some of the tracts formerly
rigated. There is considerable competition for water among irri-
tors during the dry months, and this has been one cause of the
andonment of areas formerly cultivated.

ADJUDICATION OF WATER RIGHTS.

It will readily be seen by the foregoing that the various canals and
tches taking water from Salt River have an aggregate capacity
uch larger than the low-water flow of the river, which is in the
ighborhood of 300 cubic feet per second, and the irrigable land
der these canals is proportionately in excess of the water supply
the dry season.

These facts led to the institution of a suit before Judge Joseph H.
ibbey to determine the rights of the various proprietors, the trial
which was begun in March, 1890, and concluded in August of that
ar. The amount of evidence taken in the case is very voluminous,
nsisting of 6,000 pages of typewritten matter. The argument of
e case was heard in February, 1891, and occupied fifteen days.
any interesting principles of the law relating to water rights were
unciated in this decision, relating to the method of acquiring water
ghts and the rights of the community concerning the reasonable use
opposed to the waste of water. This decision was published, but
e pamphlet is now out of print, and a portion of the decision is here
printed on account of its value and interest in connection with this
bject.

JUDGE KIBBEY'S DECISION.

In 1848, and from that time until 1863, that part of the Territory of Arizona
thin which is the Salt River Valley was a part of the Territory of New Mexico,
d there were expressly enacted by that Territory laws governing the appropria-
n and use of water for irrigation. In 1863 part of the then Territory of New
exico was erected into a temporary government by the name of the Territory of
izona, and the laws of New Mexico were, by the acts of Congress establishing
e Territory of Arizona, made applicable to that Territory.

In 1864 the First legislative assembly of the Territory convened and enacted the
de of laws commonly known and cited as the Howell Code. By article 22 of an
t of that legislature, known and designated as the "Bill of Rights," it was pro-
ded that "all streams, lakes, and ponds of water capable of being used for the
rposes of navigation or irrigation are hereby declared to be public property,
d no individual or corporation shall have the right to appropriate them exclu-
rely to their own private use, except under such equitable regulations and
strictions as the legislature shall provide for that purpose." This act went into
rce on the 1st day of January, 1865. This provision has been incorporated in

the successive revisions of our code, and is still a part of our statutory law. At the same session of the legislature, and by a law taking effect at the same time, an act governing acequias and irrigating canals was adopted.

Section 1 of that act provides that "all rivers, creeks, and streams of running water in the Territory of Arizona are hereby declared to be public and applicable to purposes of irrigation and mining," as afterwards provided.

Section 2 saves all vested rights.

Section 3 provides that "all the inhabitants of this Territory who own or possess arable or irrigable lands shall have the right to construct public or private acequias and obtain the necessary water for the same from any convenient river, creek, or stream of running water."

Section 4 provides for the assessment of damages resulting from the construction of ditches across private property of individuals.

Section 5 provides that no inhabitant of this Territory shall have the right to erect any dam, or build a mill, or place any machinery, or open any sluice, or make any dike, except such as are used for mining purposes or the reduction of metals, as provided for in sections 6 and 7 in the act, that may impede or obstruct the irrigation of any lands or fields, as the right to irrigate the fields and arable lands shall be preferable to all others, and the justices of the peace of their respective precincts shall hear and determine the question relative to all such obstructions in a summary manner and cause the removal of the same by order directed to a constable of the precinct or sheriff of the county, who shall proceed to execute the same without delay.

Section 7 directs that when any ditch or acequia shall be taken out for agricultural purposes the person or persons so taking out such ditch or acequia shall have the exclusive right to the water, or so much thereof as shall be necessary for the said purposes, and if at any time the water so required shall be taken for mining operations the person or persons owning said water shall be entitled to damages, to be assessed in the manner provided in section 6.

Section 8 prohibits the construction or maintenance of bypaths and footpaths across cultivated fields.

Section 9 provides that all owners and proprietors of arable and irrigable lands bordering on, or irrigable by, any public acequia shall labor on such public acequia, whether such owners or proprietors cultivate the land or not.

Section 10 provides that persons interested in a public acequia, whether owners or lessees of land, shall labor thereon in proportion to the amount of land owned or held by them which may be irrigated by the ditch.

Section 11 provides that animals shall be herded to prevent trespass upon cultivated fields.

Section 12 provides that in case a community desire to construct an acequia and the persons desiring to construct the same are the owners or proprietors of the land upon which they design to construct the acequia, no one shall be bound to pay damages for the land taken.

Section 13 provides for the election of overseers of public acequias.

Section 14 prescribes the manner of the election of overseers.

Section 15 provides for payment for services of the overseers.

Section 16 prescribes the duty of the overseers, of which, among others, is enumerated the duty to distribute and apportion the water in proportion to the quantity to which each one is entitled according to the land cultivated by him, and that in making such apportionment he shall take into consideration the nature of the seed sown or planted and the crops and the plants cultivated.

Section 17 provides that "during years when a scarcity of water shall exist owners of fields shall have precedence of the water for irrigation according to the dates of their respective titles or their occupation of their lands either by themselves or their grantors. The oldest titles shall have precedence always."

MAMMOTH DREDGE EXCAVATING MESA CONSOLIDATED CANAL.

ection 18 provides for the contribution of labors by irrigators to the maintece of the acequia.

ection 19 prescribes penalties for malfeasance or nonfeasance of the overseer in charging his duties, and provides for his removal in certain events.

ection 20 provides for the filling of the vacancy occasioned by the removal of overseer.

ection 21 imposes a penalty upon the owner or proprietor of land irrigated by acequia for neglect or refusal to furnish the number of laborers required by overseer for the maintenance and repair of the acequia.

ection 22 prescribes the penalties against any person who shall in any manner erfere with, impede, or obstruct any such acequia or use the water from it hout the consent of the overseer.

ection 23 provides that the fines and forfeitures recovered under the provisions the act shall be applied by the overseers to the improvement, excavation, and air of the acequia, and for the construction of bridges at points where they y be crossed by public streets or roads.

ection 24 provides for the appeal from judgment of conviction under any of provisions of the act.

Section 25. "The regulation of acequias which have been worked according to laws and customs of Sonora and the usages of the people of Arizona shall main as they were made and used up to this day, and the provisions of this apter shall be enforced and observed from the day of its publication."

Section 26 provides that plants and trees growing on the banks of any acequias all belong to the owners of the land through which the acequia runs.

Section 27 provides that any person owning lands which may include a spring or eam of running water, or owning lands upon a river where there is not popula-on sufficient to form a public acequia, may construct a private acequia for his wn uses, subject to his own regulations, provided he does not interfere with the ghts of others.

In the year 1866 the National Congress enacted a law for the disposal of its lands ntaining valuable minerals, and among the provisions of that act, with some bsequent slight verbal changes not affecting the substance or meaning, is the llowing (sec. 2339, Revised Statutes of the United States):

"Whenever by priority of possession rights to the use of water for mineral, for ining, agricultural, manufacturing, or other purposes, have vested and accrued, id the same are recognized and acknowledged by the local customs, laws, and cisions of courts, the possessors and owners of such vested rights shall be main-ined and protected in the same, and the right of way for the construction of tches and canals for the purposes herein specified is acknowledged and confirmed; it whenever any person, in the construction of a ditch or canal, injures or dam-es the possession of any settler upon the public land, the party committing such jury or damage shall be liable to the party injured for such injury or damage."

Section 2340 provides "that all patents granted, or preemption or homestead lowed, shall be subject to any vested or accrued water rights, or rights to ditches reservoir used in connection with such water rights, as may have been acquired der or recognized by the preceding section."

This provision of the act of Congress has been held by the Supreme Court of e United States, and of some of the States, not only to confirm rights that ve been initiated or had vested prior to the passage of the act, but that it was ntinuous in its operation and was the license of the Government to persons to reafter appropriate water on the public domain for agricultural, mining, man-facturing, or other purposes. (98 U. S., 453; 13 Oregon, 596.)

On the 3d of March, 1877, there went into effect an act of Congress providing at any citizen of the United States, or any who had declared his intention to

become such, upon the payment of 25 cents per acre, may file a declaration, with the register and receiver of the land district in which any desert land is situated, of his intent to reclaim a tract of land not exceeding one section, by conducting water thereon within the period of three years thereafter. It provides that the right to the use of the water by the person so conducting the same on or to any tract of desert land of 640 acres "shall depend upon bona fide prior appropriation, and such rights shall not exceed the amount of water actually appropriated and necessarily used for the purposes of irrigation and reclamation, and all surplus water over and above such actual appropriation and use, together with the waters of all lakes, rivers, and other sources of water supply upon the public lands and not navigable, shall remain and be held free for the appropriation and use of the public for irrigation, mining, and manufacturing purposes, subject to existing rights."

By an act of the legislative assembly of the Territory of Arizona approved February 19, 1877, all the laws of the Territory then in force were directed to be recompiled, which was done; and the compilation is known and cited as the "Compiled laws of 1877," among which are the Bill of Rights and the various provisions governing the construction of private and public acequias and the appropriation and use of water for irrigation that we have above quoted from the Howell Code. The same laws have been carried forward into the revision of 1887. In 1887 the acequia law was not reenacted, but not having been repealed, it is still in force, and the editors of the revision of 1887 have incorporated it in that revision. (Sects. 3199–3226, R. S., 1887, Arizona.)

In 1887 the legislative assembly enacted a law providing that the common-law doctrine of riparian rights shall not obtain or be of any force or effect in this Territory. (Sec. 3198, R. S., 1887, Arizona.)

* * * * * * *

REASONABLE USE OF WATER.

Incident to the right of the inhabitants of this Territory to appropriate water for irrigation or other uses is the restriction that the means of diversion shall be reasonably adapted to the purpose, to the end that the water that is made free to the public shall not be diminished beyond the quantity sufficient to supply the actual needs of the appropriator; that the means of application of the water to the purposes for which it is appropriated shall be of a character to insure as small a consumption of water as is reasonably consistent to the accomplishment of the purpose. No man has a right to waste a drop of water. Any excess of water that he diverts and wastes by carelessness, negligence, or ignorance of economic methods of cultivation or irrigation, or failure to adopt them, he unlawfully diverts.

It appears from the evidence in this case that large quantities of water are allowed to flow in the various canals and ditches to supply stock with water. This necessarily involves a great waste of water. At a small estimate, I should think the evidence discloses an amount of water wasted thus sufficient, if properly applied to irrigation, to make productive 10,000 acres of land. The amount of water actually consumed by the stock is insignificant. The loss is that due to evaporation and seepage in its long passage through the various canals and the miles of subsidiary ditches. This seems to me to be an unreasonable use of water. I do not mean to deny the right to the use of water for stock, for it has always been a recognized use, like that for domestic purposes. But it can not, I think, be diverted from its original course for that purpose. It has always been the law that stock and the public could drink from a water course, but not to impede its flow or diminish its quantity for that purpose. Instead, I consider the law to be, to bringing the water diverted from a natural water course a long distance by means necessarily involving an enormous proportionate waste to water stock, the stock must be taken to the natural water course to drink, or otherwise provided for.

DIVISION BOX ON TEMPE CANAL

f the water be in the ditches on a man's ranch in the course of application ectly to irrigation, it might be permitted to allow stock to drink of it; but it an unreasonable use of it to permit water to be in the ditches for that purpose ne.

Another matter for our consideration in this connection is the right of the propriator of water to the exclusive possession, maintenance, operation, and the e of the conduit, as he has prepared it, for the diversion of the water, whether not, having constructed such a conduit, he thereby has the right to have the ater flow in the river to that conduit and thence to the point where he desires use it, or whether his right is limited to the actual delivery of water to his nds, with or without increased expense to himself, whether it be by means there- r provided by himself or by means provided by some one else. To illustrate: If ose who operate the Highland Canal should divert from the river the water to hich the consumers under the Tempe, the Mesa, the Utah, and the San Fran- sco are entitled, and yet should that company deliver the water so diverted rough its own canal to and upon the lands of those under the other canals named, the quantities to which they are entitled, would those who constructed and nce have operated and maintained the Tempe Canal, the Utah Canal, the Mesa anal, and the San Francisco Canal have any just cause for complaint, or have e owners of those mentioned canals a vested right not only to the use of the ater for the purpose of irrigation, but also to have it conveyed by means of its vn conduit?

Following out to their sequence the propositions I have advanced as to the own- ship of water and the right of appropriation, I am of the opinion that the entire ght of the appropriator for irrigation is limited to the delivery of water sufficient r the purpose upon his land at a point where he can use it for irrigation, and at so long as such water is so delivered he may be indifferent to any acts of version or obstruction of the flow of water in the natural water course, and has just cause for complaint therefor. He might be compelled to adopt a more pensive means of delivery of the water to his lands if the means that he has ready adopted are such as would result in the loss of water; for, as we have peatedly affirmed, the water is public property; it is a common stock to which l may go, and no man has any right by faulty construction of his conduits, or r their deficient construction, or by a desire to appropriate more than his share the water, to diminish that common stock of the water to any greater extent an his necessities require.

This brings us to the question whether or not it is the duty of the prior appro- iator to make use of such new means as may result in the more economical con- yance of water than those which he had heretofore provided for himself. hether or not it would be his duty, if, for instance, he was an irrigator under e Tempe Canal, to construct a new conduit from the Highland Canal to his nds, and thereby conduct his water at a considerable saving of the common ck of water, assuming, of course, that the Highland Canal is capable of carry- g, in addition to that which it is already under obligation to carry, the quantity fficient for his use.

The variety of means adopted for the diversion of water vary under different nditions. The person who first appropriates usually finds in the natural water urse a volume of water in excess of that which he himself needs, and to divert e comparatively small proportion of the whole volume which he may need uld be inexpensive and easy of accomplishment. It is usually unnecessary for e first appropriator to construct a dam, or that he should excavate a ditch to the ttom of the water course whence he divert his water; because of the superabun- nce in the natural water course enough for his purpose may be diverted by less pensive means. As, however, others seek, subsequently, to appropriate a

portion of the same stream above the point of diversion by the first, a diminution of the quantity of the water going down to the first appropriator results in such a reduction of the volume of water that the means adopted by the first appropriator will not enable him to continue his diversion, and he must, in order to get the water, either construct a dam so as to divert the water or excavate his ditch deeper, so as to reach and divert the water from the diminished quantity flowing in the natural water course. This would, of course, entail an additional expense upon the first appropriator.

To illustrate the question, let us suppose that upon a water course there is an average flow of water of 4 feet in depth; that the construction by the first appropriator of a ditch, the bottom of which is 2 feet below the surface of the water, enables him thereby to divert all the water he needs. Suppose that thereafter another appropriator constructs above the point of diversion by the first a ditch which appropriates 2 feet in depth of the water, and diminishes it so in volume that instead of flowing by the point of diversion by the first, 4 feet in depth, it now flows only 2 feet in depth. Still the quantity there flowing is sufficient to supply the needs of the first appropriator. It will be seen that the first appropriator can not, by the means then had, divert his amount of water, and there is necessarily entailed upon him an expense of either further excavation of the ditch or the erection of a dam in order to raise the surface of the water to a point at which it can be diverted into his ditch; and this additional expense is entailed by the act of the subsequent appropriator. It is not a question, as I have put it, of a deficiency in the supply of water, but it is merely a question of the right of a subsequent appropriator to diminish the volume of water flowing to such an extent that it can not be diverted by a prior appropriator by the means he then had. We think that it certainly can not be said that the first appropriator has the right to have the water flowing such a way that by his first means of diversion he can still continue his appropriation of the water. The whole policy of the law is, that all of the waters in the streams in this Territory should be used for mining, agricultural, and milling, and that there shall be no appropriation by anyone in a manner that shall prohibit subsequent appropriation by others, unless that subsequent appropriation leaves an insufficient quantity of water.

The court held that the title to irrigating water inheres in the land irrigated and not in the company diverting the water, and that priority of time at which the water was applied to beneficial use constitutes priority of right to use of said water, and that this priority was determined, not by the date of diversion from the river, but by the date of such actual beneficial use. Evidence was therefore taken to establish the date of actual irrigation of each tract of land under each canal, the date of such irrigation determining the beginning of the right to the quantity of water requisite for such irrigation. Each canal, therefore, was entitled in any given year only to such quantity of water as was necessary to irrigate the lands actually under cultivation, subject to similar rights of other lands previously acquired. The unit of area for this purpose was taken as 160 acres, or a quarter section, although fractions of such tracts were considered in rendering the decision, the lowest subdivision considered being 40 acres, or one-fourth of a quarter section. The duty of water was assumed as 64 miner's inches for a quarter section of land. A miner's inch was defined to be one-fortieth of a cubic foot per second, which made the duty of 1 cubic foot per second 100 acres. On this basis a decision

IRRIGATION SCENE

from which the following table was constructed, under the
he court:

ıg for each year the number of quarter sections under each canal entitled to water from Salt River as per decree of court.

	Salt River Valley Canal.	Maricopa Canal.	Tempe Canal.	San Francisco or Wormser Canal.	Utah Canal.	Mesa Canal.	Grand Canal.	Arizona Canal.	Total Number of quarter sections for each year.
.....	12½	1	.....	.....	.....	.....	.....	.....	13½
.....	22	6	.....	.....	.....	.....	.....	.....	28
.....	31½	14½	.....	.....	.....	.....	.....	.....	46
.....	48	24½	5	8	.....	.....	.....	.....	85½
.....	78½	28½	49	8	.....	.....	.....	.....	167
.....	90½	29	57	12	.....	.....	.....	.....	188½
.....	90½	31	57	12	.....	.....	.....	.....	190½
.....	90½	32	57	12	.....	.....	.....	.....	191½
.....	92½	36	57	12	.....	.....	.....	.....	197½
.....	95½	41	57	22	7	.....	.....	.....	222½
.....	102	53	67	22	24	23	2	.....	293
.....	104	65½	70	22	24	30	15	.....	330½
.....	109	84½	70	24	24	35	17½	.....	364
.....	116½	102	72	24	24	43	18½	.....	400
.....	117½	117½	90	27	26	50	23½	.....	451½
.....	118½	124½	90	28	38	59	43½	.....	501½
.....	119½	128½	95	28	38	62	45½	.....	516½
.....	120½	133	98	28	38	73	46½	43½	580½
.....	121½	135	105	29	38	75	47½	105½	656½
.....	122½	134	113	31	40	82	47½	192½	765½
.....	123½	139	117	31	55	82	48½	333½	929½
.....	123½	139	117	31	55	82	48½	350	946

.res in the columns headed Salt River Valley Canal, Mari-
l, etc., indicate the number of quarter sections irrigated in
esignated in the column on the extreme left. Bearing in
; priority in time denotes priority in right, it will be seen
ugh the oldest water rights are in the Salt River Valley and
canals, such priority extends only to the quantity of water
for those tracts which were irrigated previous to lands irri-
er other canals. Thus in 1873 the area irrigated under the
Valley Canal was increased by 12 quarter sections over that of
the additional water necessary for this increase was second-
ıt to all lands irrigated in 1872, whether under the Tempe,
ser, or the Maricopa Canal. It will be seen that 516½ quar-
ıs, or 82,640 acres, were irrigated in 1884, requiring under
icated duty of water 826 second-feet. In addition to this,
mill was entitled to 1,100 inches, but this amount need not
ed from the irrigating supply of the river, because the water
len's mill returned to the river above the head of the oldest
l could be rediverted by them for irrigation.

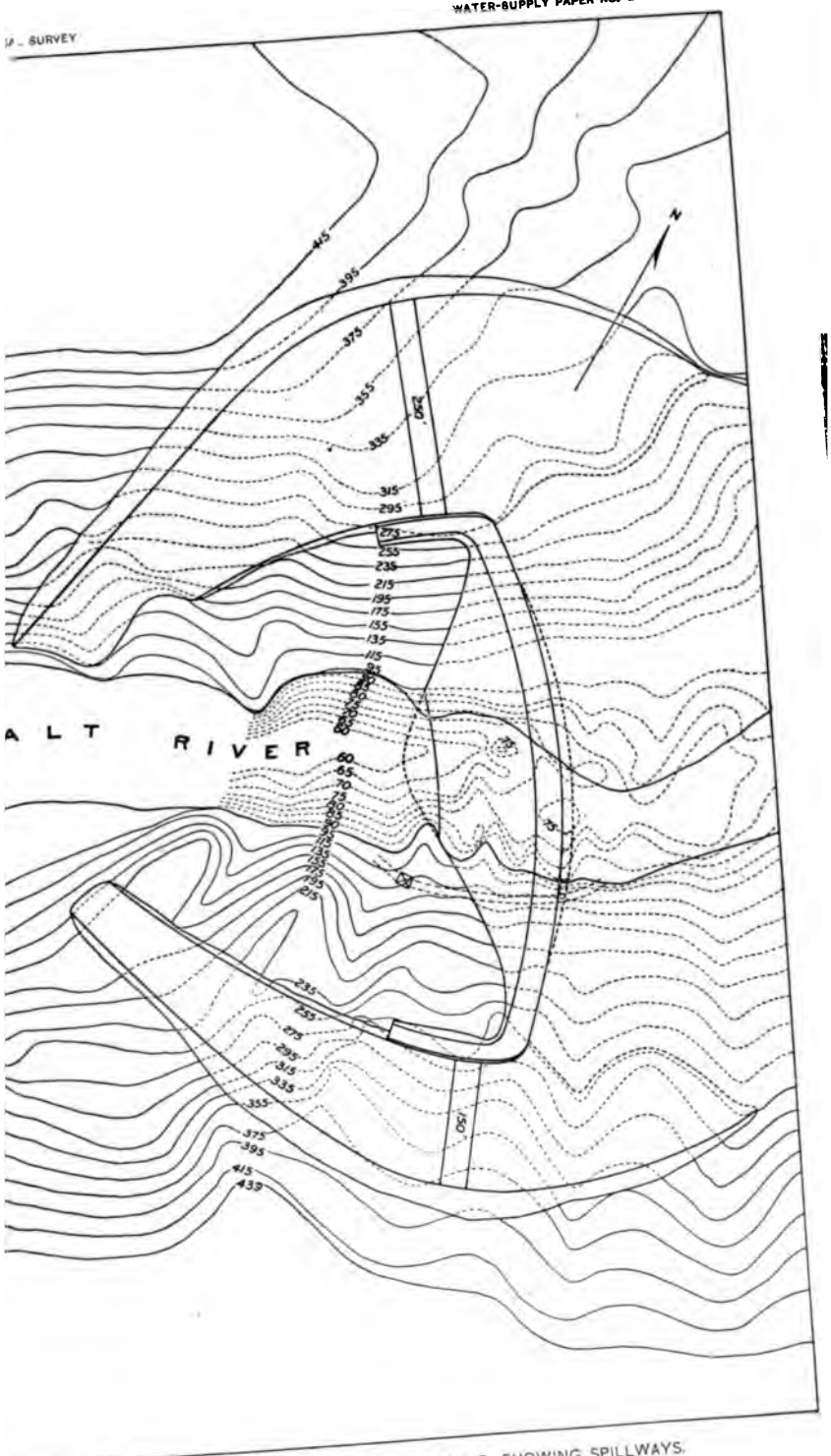
Considerable effort has been made by the later-constructed can particularly the Arizona and Mesa Consolidated, to establish claim what is called the surplus waters or flood discharge of Salt Riv These rights are of somewhat doubtful value for any purpose which these canals can put them, for the high waters embraced such claims are of short duration and can not be utilized to matu any crop. They are used for "soaking up" the ground during t period of high water in the hope that a portion of the moisture will retained by the soil to mitigate the drought through the low-wat season, when such waters can not be applied. It is obvious that su a use of waters is not a use at all, but a waste. It is not especial objectionable at present, except that in some instances farmers a thus encouraged to plant crops which can be matured only by the u of water obtained either illegally or through the generosity of so of the older proprietors. What standing such claims to the surpl waters can obtain in the courts remains to be seen. If they are su tained, the result will be disastrous to the future development of ir gation, for it is these surplus waters upon which any project f storage on the upper waters of the Verde and Salt rivers must larg depend. Such storage works will hold the surplus waters for u during the dry season, when they are most needed, but if title is h in the manner claimed, they will probably continue to be wasted at present.

IRRIGATION WORKS PROJECTED.

Having noted the principal irrigating systems taking water fr the Salt and Gila rivers, and reviewed in a general way the dema for water and the claims made upon the flow of these streams, pertinent to discuss at some length the attempts now being mad increase the available water by means of reservoirs and other w designed to save in part the waste water occurring in floods. principal projects which have been surveyed by individuals and porations or examined by the Government are known as the Verde, Tonto Basin, Walnut Grove, Agua Fria, Cave Creek, Bu Lower Gila, and Queen Creek.

RIO VERDE.

This enterprise contemplates the storage of waters at the site o Rio Verde known as the Horseshoe Reservoir, in T. 8 N., R. 6 E., and Salt River meridian. The drainage area tributary to this r voir is nearly 6,000 square miles. The proposed height of the at this point is 150 feet above the present surface of the river, a will extend to a maximum depth of 25 feet to bed rock. It w 386 feet long at the low-water line of the river, and 1,250 feet the top. It is proposed to build this dam of a rock-filled type h side slopes of 2 : 3, made impervious on the water side by a she asphalt pavement extending to bed rock. The spillway is situate



PLAN OF PROPOSED DAM ON SALT RIVER, SHOWING SPILLWAYS.

300 feet west of the dam and is separated from it by a mass of rock rising over 75 feet above the spillway. It will be about 1,000 feet long. This reservoir will have a length of about 6 miles, a surface area of 3,402 acres, and a capacity of 204,935 acre-feet, as shown by the following table, which gives the area and capacity for each 10 feet elevation of the surface:

Area and capacity of Horseshoe Reservoir.

Contours.	Area, in acres.	Acre-feet between contours.	Total capacity in acre-feet.
10	39	270	270
20	99	690	960
30	268	1,835	2,795
40	442	3,550	6,345
50	720	5,810	12,155
60	974	8,470	20,625
70	1,178	10,760	31,385
80	1,398	12,880	44,265
90	1,665	15,315	59,580
100	1,916	17,905	77,185
110	2,109	20,125	97,610
120	2,349	22,290	119,900
130	2,646	24,975	144,875
140	2,982	28,140	173,015
150	3,402	31,920	204,935

Work upon the dam itself has not yet been begun, but the outlet tunnel is completed. It is intended to divert the river through this tunnel when necessary to complete the foundations. The tunnel is 55 feet long, 12 feet in diameter, with open-cut approaches.

About 18 miles below the Horseshoe Reservoir the water is to be diverted from the river by a dam 90 feet high and 475 feet long, of the rock-filled type. Here the canal is to head with a bottom width of 25 feet, depth of water 8 feet, side slopes 1 : 1, and a fall of 0.0003. The estimated mean velocity is to be 3 feet per second and the capacity 800 cubic feet per second. This section is continued for a distance of 54 miles, a considerable part of the distance being through rough country, with very heavy construction. At the end of the 54 miles the bottom width is reduced to 20 feet, and this width is maintained 15 miles farther to the crossing of New River. At New River it is proposed to construct another reservoir, partly to impound the storm waters of this stream, which is ordinarily dry, and partly to receive the waste waters from the canal. The proposed dam for this reservoir will be 100 feet high, with a top length of 1,800 feet, which it is said will impound over

100,000 acre-feet of water. It is not intended to construct this reservoir at present, but it is contemplated as a future possibility after the development of the upper portion of the project. It is proposed to continue the canal from this reservoir on a grade line across the Agua Fria River, round the base of the White Tank Mountains, and across the Hassayampa, and to utilize another reservoir west of the Hassayampa, just above the Buckeye Canal, near the Four Buttes, which it is proposed to fill by a lateral feeder from the main canal. The land under this canal between Agua Fria and the Hassayampa rivers, as shown on the map, it is also proposed to irrigate from the Agua Fria Land and Water Company's works. The conflict of interests here, however, is more imaginary than real, as there is abundant good land to utilize all the water that can be furnished by both these projects and any others that may be constructed.

The estimated cost of the dam for the Horseshoe Reservoir is $600,000; the diversion dam is estimated to cost $200,000, and the canal to the Hassayampa is estimated to cost about $1,200,000, making $2,000,000 in all, exclusive of the two reservoir sites in the plains. It is estimated that from the head-gates to the Agua Fria River the canal covers an area of 125,000 acres of irrigable lands, including a very desirable tract of nearly 50,000 acres in Paradise Valley. West of the Agua Fria the land to be irrigated is an almost unbroken plain of sandy loam, and comprises more than 125,000 acres above the Buckeye Canal and east of the Hassayampa. As above stated, this project is under construction, the greater part of the work already done being upon the canal. The magnitude of the undertaking, the natural difficulties to be overcome, and the prevailing business depression combine to render its prosecution a matter of peculiar difficulty.

The company claims to have sold water rights for about 100,000 acres at prices varying from $10 to $18 per acre, paid for at the rate of $1 down and $1 per year thereafter. The payment of this $1 per acre each year is considered to be a sufficient compliance with the law requiring a person entering desert land to expend a certain amount in the use, irrigation, reclamation, and cultivation of the land. After the works are constructed the owners of the water right are to pay a certain amount per quantity of water used, the unit of measurement being the cubic foot. The rate charged is to be a gradually increasing one from $1.21 up to $2.42 per acre-foot after ten years. The maximum amount of water which can be demanded in any one year is at the rate of 2 acre-feet for each acre irrigated.

THE TONTO BASIN PROJECT.

Just below the junction of Tonto Creek with Salt River, near the line between Gila and Maricopa counties, Salt River passes through a deep, narrow gorge of solid rock. Above this point both streams flow through wide, level valleys, which are settled and cultivated

VIEW IN CANYON OF SALT RIVER BELOW MOUTH OF TONTO CREEK.

considerable extent. The Hudson Reservoir and Canal Company has made surveys and estimates, contemplating the construction of a dam at this point (fig. 9) about 215 feet high from bed rock and 610 feet long on top, which it is claimed will give a reservoir capacity of over 800,000 acre-feet. A spillway is to be cut around each end of

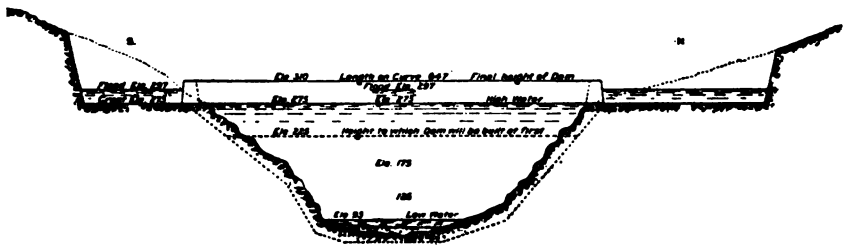


FIG. 9.—Elevation of proposed dam on Salt River.

this dam, as shown in Pl. XXI. It is proposed, first, to build a dam of an ogee section (fig. 10, *a*) about 140 feet in height, heavy enough to form the base of the dam of the full height, and to allow the flood water to pass over its crest after the reservoir fills. After the waters impounded by this reservoir have been disposed of the dam will be completed (fig. 10, *b*) and the additional waters will be sold.

Several lines have been surveyed for the location of a canal to con-

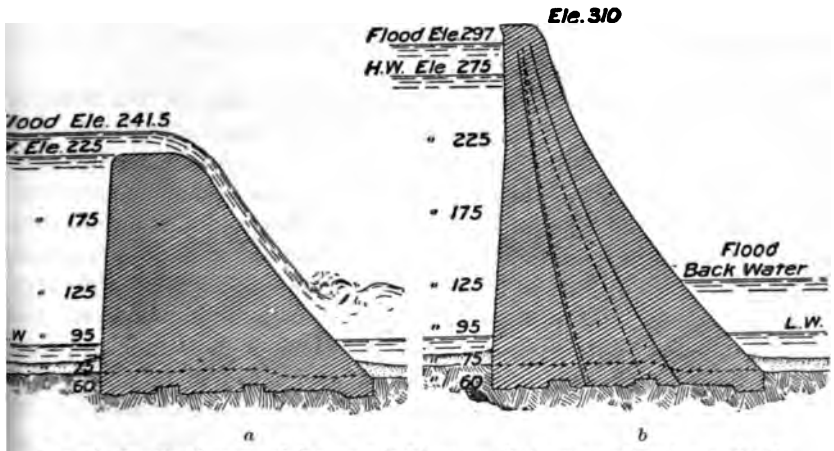


FIG. 10.—Profile of proposed dam on Salt River. *a*, first construction; *b*, completed.

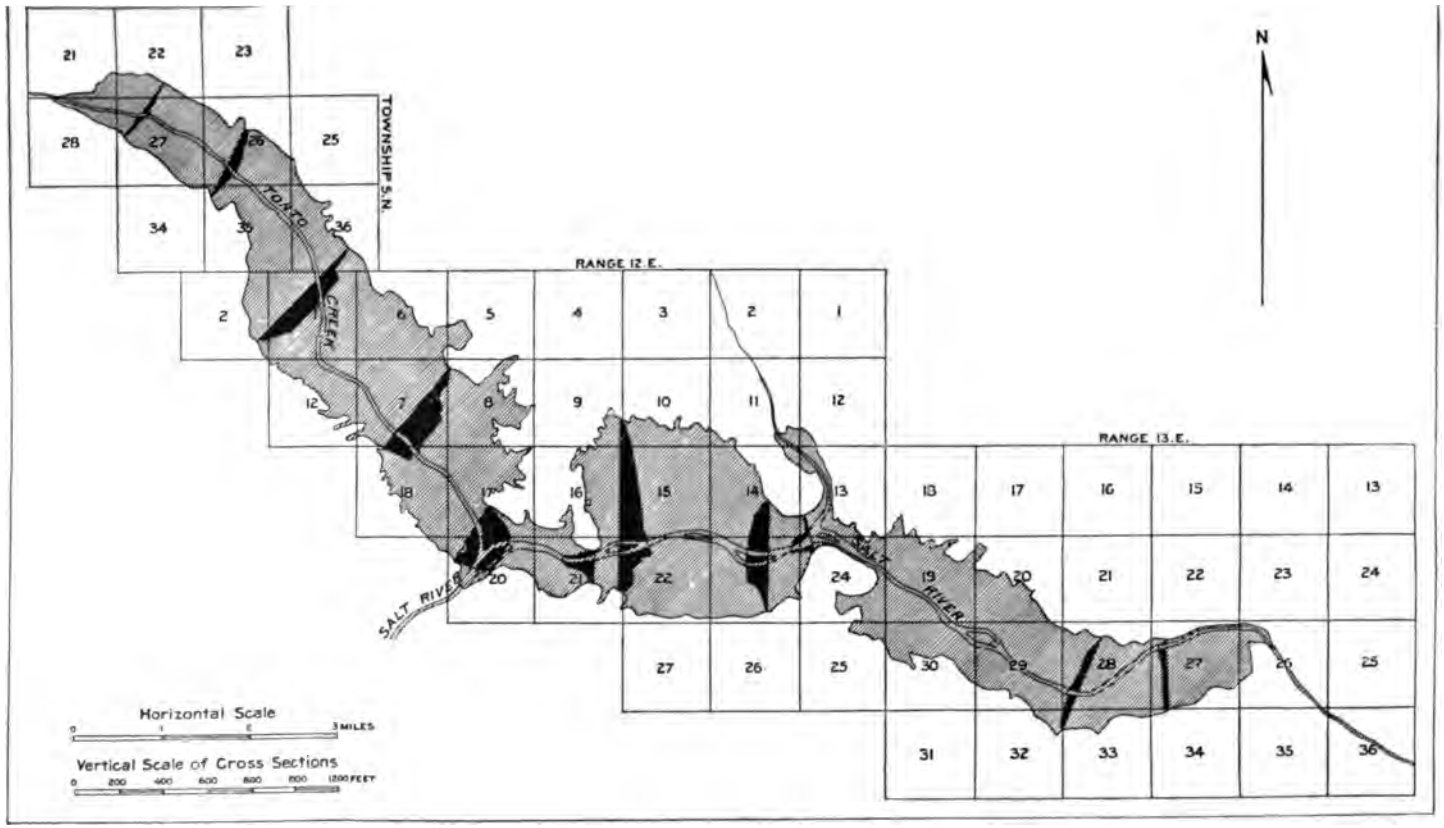
duct these waters to irrigable lands on the south side of the river, and it has been shown that by diverting the waters well up in the canyon of Salt River they can be delivered high enough to water a large tract of land at present not under canal and to irrigate the greater portion of the valley lands on the Pima Indian Reservation. This involves a

large amount of costly construction in the canyon, and it is not probable that such a line will be found advisable. Large tracts of uncultivated land are already under existing canals, particularly the Arizona, the Mesa Consolidated, and the Highland canals. Many of the older canals have also under them considerable tracts of uncultivated lands for which they hold no water right, and whatever waters are left after supplying all these demands can be distributed from the line somewhat higher and parallel to the Highland Canal without involving much heavy construction.

It would probably be impossible to find anywhere in the arid region a storage project in which all conditions are as favorable as for this one. The capacity of the reservoir, in proportion to the dimensions of the dam, is enormous. The lands to be watered are of remarkable fertility, in a climate which may be classed as almost semitropic, and are vastly greater in area than the water can supply. To a considerable extent they are already settled upon, and the water is in lively demand. The character of rock at the dam site is said to be excellent for the construction and foundation of the dam. There is tributary to this reservoir about 5,756 square miles of mountainous country, ranging in altitude from 2,000 to 12,000 feet, and including some of the best drainage area in Arizona. Many of the tributaries of Salt River find their source at the foot of the bold escarpment of the Mogollon mesa. Tonto Creek, for instance, heads at the foot of this mesa with the volume of a very considerable rivulet within a few hundred yards of the divide. Such streams evidently obtain considerable water supply from the precipitation which falls north of the divide, as pointed out on page 16.

These facts indicate that the watershed tributary to this reservoir is not only large but favorable to a high percentage of run-off. It is doubtful, however, whether the immense reservoir capacity above referred to could be filled in the driest years, and what proportion of its capacity should be held as a reserve for years of minimum run-off can not be determined exactly without a long series of measurements of the discharge of Salt River between the mouth of the Verde River and the mouth of Tonto Creek. Such measurements have been roughly carried on for over a year by the Hudson Reservoir and Canal Company, and the results, so far as observed, are given on page 39, but the series is too short to justify a positive expression on this point. There can be no doubt, however, that in this reservoir site lies one of the most important possibilities for the future of the agriculture of southern Arizona.

Pl. XXIII shows the outlines of this reservoir site as surveyed. The shaded portions represent cross sections on the lines indicated.



TONTO RESERVOIR SITE, SHOWING ELEVATIONS OF TEN CROSS-SECTIONS OF THE RESERVIOR.

Area and capacity of Tonto Reservoir.

Height above low water.	Capacity, in acre-feet.	Surface, in acres.	Elevation above sea level.
25	4,400	330	1,950
30	6,100	420	.....
35	9,000	570	.....
40	11,900	730	.....
45	16,200	890	.....
50	20,000	1,030	1,975
55	26,900	1,280	.....
60	33,300	1,510	.....
65	42,000	1,740	.....
70	50,700	1,980	.....
75	62,100	2,300	2,000
80	73,500	2,610	.....
85	88,500	3,010	.....
90	103,600	3,430	.....
95	122,700	3,820	.....
100	141,800	4,210	2,025
105	164,700	4,610	.....
110	187,700	4,990	.....
115	214,700	5,430	.....
120	241,800	5,860	.....
125	272,800	6,210	2,050
130	303,900	6,570	2,055
135	338,600	6,950	.....
140	373,400	7,350	.....
145	413,000	7,930	.....
150	453,000	8,530	2,075
155	498,000	9,110	.....
160	544,000	9,680	.....
165	594,000	10,170	.....
170	645,000	10,680	.....
175	701,000	11,240	2,100
180	757,000	11,750	2,105
185	820,000	12,300	.....
190	880,000	13,000	.....
195	950,000	13,600	.....
200	1,020,000	14,200	2,125

WALNUT GROVE RESERVOIR.

A storage reservoir was built on the Hassayampa River jus the settlement of Walnut Grove in 1888. The dam (fig. 11) feet long on top, 138 feet wide at bottom, 15 feet in width on t 110 feet high. As shown in Pl. XXIV, it was of the rock- placer-mining type, consisting of a front and back wall of d carefully laid with loose rock filling between. A wooden she ered the water slope to make it water-tight. This covering

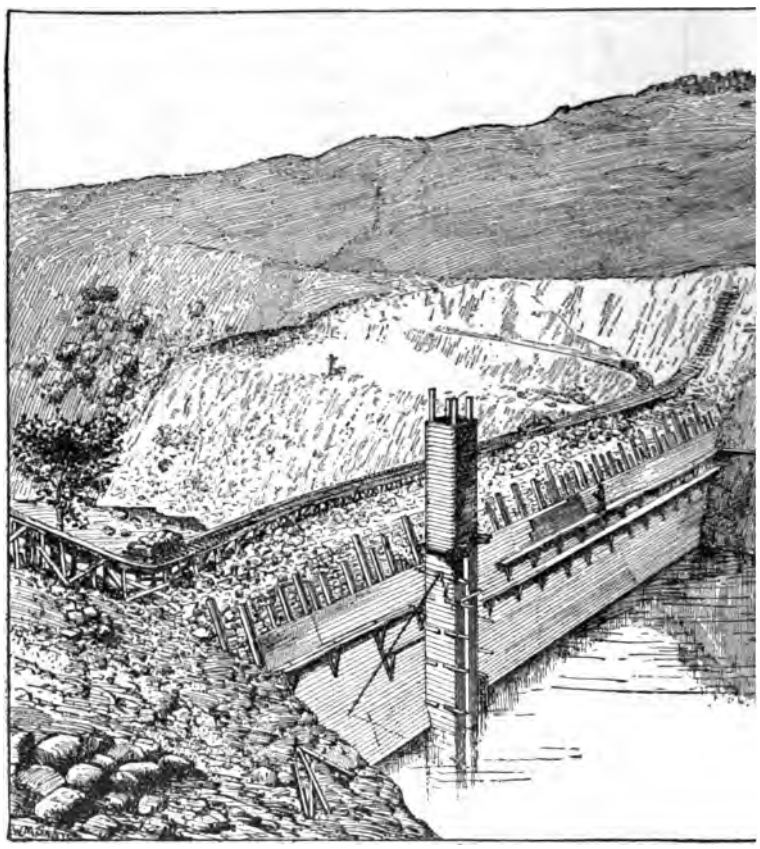


FIG. 11.—View of Walnut Grove dam.

tened to vertical stringers about 8 by 10 inches, which in tu bolted to the projecting ends of heavy logs built into the up the stringers being about 4 feet apart (fig. 12). The sheath sisted of two thicknesses of 3-inch planking, with tarred pa between the two. The outer face was calked and cover paraffin paint. Owing partly to the insufficiency of the spill partly to its becoming obstructed with driftwood, the great

WALNUT GROVE DAM.

'y, 1890, overtopped this dam, causing it to fail. The capacity 'eservoir has been variously estimated at from 7,000 to 14,000 t. Its destruction caused the loss of twenty-six lives and a rable quantity of property in the valley below. A new reser- ıld doubtless be constructed on the same site which would at least 5,000 acres of the land.

AGUA FRIA PROJECT.

ıgua Fria Water and Land Company's project contemplates struction of two reservoir dams and one diversion dam on

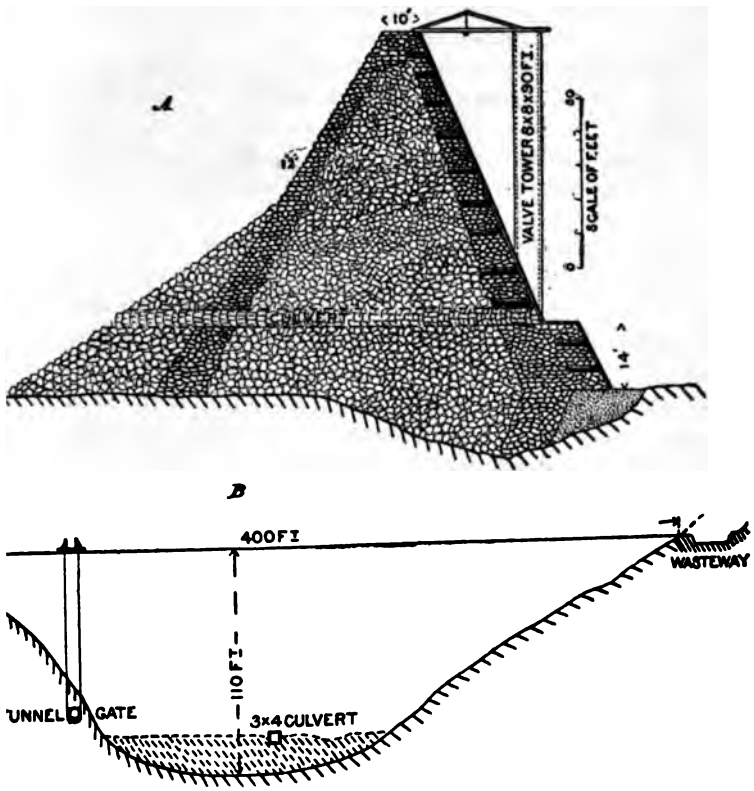


FIG. 12.—Cross section and elevation of Walnut Grove dam.

ria River. The diversion dam, a view of which is given in Pl. ı already nearly completed. It is built of rubble masonry, laid ır made with a natural cement burned 25 miles southwest of site, at the foot of the White Tank Mountains. The masonry ɔut $4 per cubic yard, the stone being placed by cable con- s shown in the plate. The total length when completed will

be 650 feet, the greatest height above the creek bed 40 feet, in add tion to which the deepest excavation to bed rock was 40 feet. Tl greatest width on bed rock is 53 feet. A spillway is to be provid around the west end. The upstream or back of the dam is vertic The lower batter is 12½ in 20. Two sluices are left at the surface the stream bed, each 4 feet wide by 6 feet high, to dispose of the flo ing waters. The top width when completed will be about 8 feet. October, 1895, a great flood came down the river, which the sluicewa were unable to discharge and which poured over the dam for seve hours to a depth of more than 8 feet, finally carrying out a portion the recently completed masonry, about 12 by 100 feet, near the we end of the dam. The portion remaining below that carried away e hibits a smoothly plastered surface with no evidence of fracture indication of having been bonded in any way to the destroyed sectio The rubble masonry contains numerous horizontal joints finish and plastered as smooth as though intended for a floor, apparent diminishing the bond with the next course above. This seems be in direct contravention of good engineering practice, and to count in a measure for the failure of the portion of the dam abc mentioned.

The canal heads at the east end of the dam in a cut 16 feet deep solid rock, and is constructed for a distance of about 4 miles. At t point it is intended to carry the canal across the river in a flume ' feet long, and to extend it in a southwesterly direction around t foothills of the White Tank Mountains toward the Hassayampa Riv The constructed portion of the canal is 18 feet wide on bottom, and intended to carry 8½ feet of water. The grade is 0.0004 or 2.11 f per mile, and the capacity is intended to be 400 cubic feet of wa per second. A large lateral is to be taken from the east side of t main canal about 2½ miles from the head, to extend southward the service of the lands on the east side of the river.

The first reservoir dam is to be located 1¼ miles above the divers dam, at an old stage station known as Frog Tanks. A fairly good d site occurs here, with rock abutments, and the bed rock is said to near the surface. It is proposed to build this dam to a height of feet, and it is claimed that this will impound about 50,000 acre-f of water. No considerable amount of work has been done upon t dam other than excavating pits on the slopes and making soundi to ascertain the depth to bed rock in the bed of the river. Quarr have been opened and a large amount of rock has been quarried a prepared for the work. The construction of this dam is to foll immediately after the completion of the diversion dam.

Eight miles above this place another dam site is located, in a go through solid rock, 262 feet wide at the bed of the river, and but feet wide at a height of 200 feet. It is said that this basin w impound, with a dam 150 feet high, over 150,000 acre-feet of wat

DIVERTING DAM ON THE AGUA FRIA.

he plans of this irrigation project appear to be open to criticism, by continuing the canal 1¼ miles farther up the canyon it would e reached the lower reservoir dam site, which is the next struc- contemplated in the plans, and which would have served as a ersion dam, and the cost of the dam already constructed might s have been saved. The construction of the canal through this ance would be expensive, as the country is rough, but it certainly ld not approach in cost that of the diversion dam. Moreover, n in use the diversion dam will require to be filled to a height of rly 40 feet above the bed of the creek to reach the intended height he canal. This will form a pond of probably 40 or 50 acres con- ntly exposed to evaporation in this warm and arid climate. This is worth considering, for the water supply is the limiting feature his enterprise, the capacities of the reservoirs and the land to be gated being relatively much greater than the water supply to be ended upon.

CAVE CREEK PROJECT.

he Pennsylvania Irrigation Company proposes to build a dam 100 high in the canyon of Cave Creek, which it is said will form a res- oir of more than 100,000 acre-feet capacity. The water is to be erted about 7 miles below and used in the irrigation of the lands in adise Valley above the line of the Rio Verde Canal. As this drain- area is estimated to be only about 200 square miles, it seems improb- that this area will furnish sufficient water to justify the construc- of a reservoir of this capacity; but a reservoir can doubtless be t at this point which will impound all the waters that can be ended upon from its drainage, and the land to be watered is abun- and excellent.

THE BUTTES RESERVOIR.

t a point about 14 miles east of Florence the Gila River passes veen two buttes locally known as "The Buttes." For many years as been proposed to build a dam at this point to store the flood ers of the Gila River for the reclamation of the arid plains below. s project was investigated by the writer in 1896 in connection with water supply for the irrigation of the Pima Indian Reservation.[1] etailed survey was made of the gorge through which the river es, for the purpose of determining the best point for a dam and imensions and cubical contents. The scale adopted was 50 feet n inch and the contour interval 2 feet, except where the slopes too precipitous for this interval, when only 10-foot contours were rn. After the completion of this survey the reservoir site to an ation 200 feet above the bed of the river in the gorge was mapped

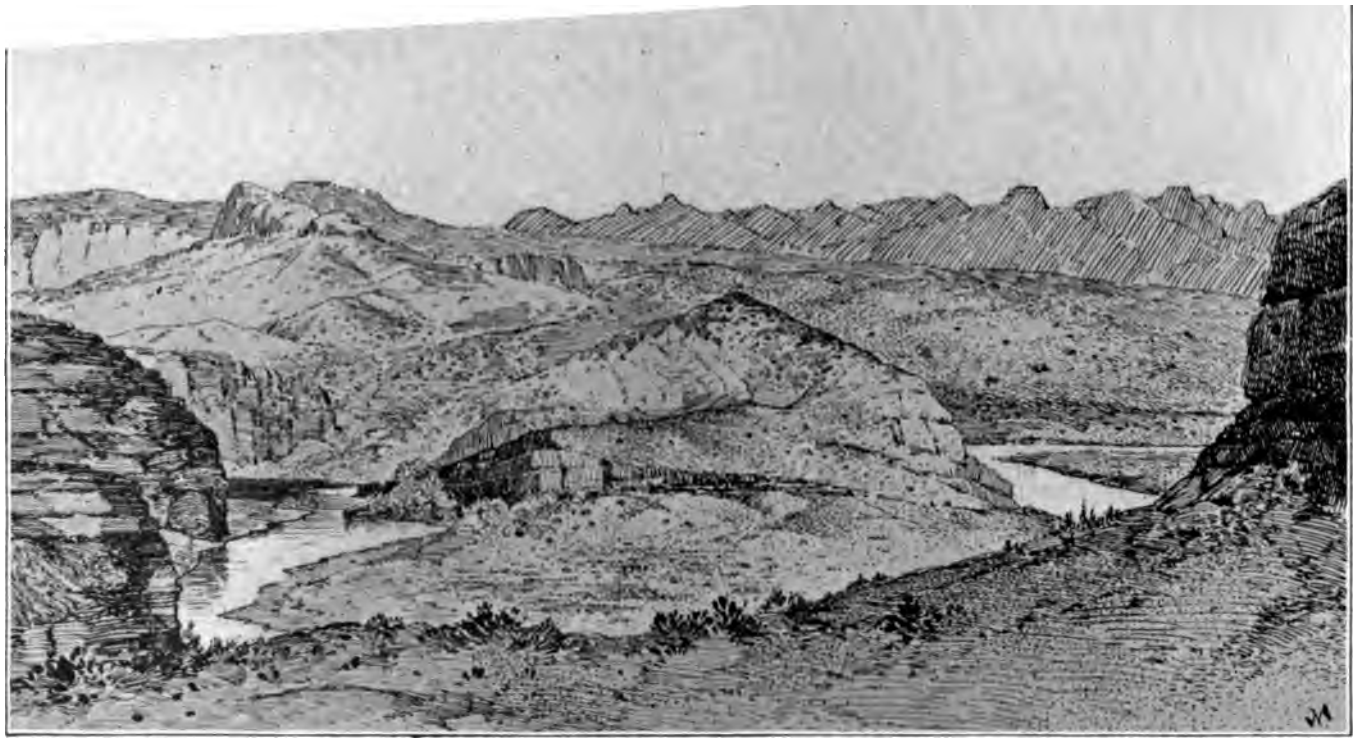
[1] Fifty-fourth Congress, second session, Senate Doc. No. 27.

on a scale of 5 inches to a mile in 10-foot contours. The rese capacities obtained by this survey are as follows:

Area and capacity of The Buttes Reservoir.

Contour flow line.	Area, in acres.	Capacity of section, in acre-feet.	Total capacity, in acre-feet.
10	20	100	100
20	71	450	550
30	229	1,500	2,050
40	397	3,130	5,180
50	538	4,650	9,830
60	741	6,370	16,200
70	928	8,345	24,545
80	1,105	10,165	34,710
90	1,329	12,170	46,880
100	1,566	14,475	61,355
110	1,769	16,675	78,030
120	2,029	18,990	97,020
130	2,367	21,980	119,000
140	2,746	25,565	144,565
150	3,149	29,475	174,040
160	3,602	33,755	207,795
170	4,118	38,600	246,395
180	4,609	43,635	290,030
190	5,133	48,710	338,740
200	5,651	53,920	392,660

Eleven soundings for bed rock were made at the dam site by ing iron rods into the gravel. What was supposed to be bed was reached at a maximum depth, near the center of the river, feet. The site proposed for this dam is where the river ente gorge (Pl. XXVI), between the end of a projecting ridge on th and a solid igneous dike on the west. It is proposed to buil dam to a height of 170 feet above the bed of the river, or 235 feet bed rock. The top width is to be 12 feet; the upstream or back is to be 1 in 20, the face slope 1 in 2 from the top to a point 8 below the top, and 2 in 3 from that point to bed rock, as shown i 13. A spillway capacity of over 100,000 cubic feet per second be provided, partly to the east and partly to the west of the Both spillways will discharge their waters clear of the dam. reservoir will have a capacity, as shown in the above table, of 2(acre-feet above the outlet tunnel, which will be about 30 feet a the bed of the stream. The outlet tunnel will pierce the hill t southwest of the dam, and will be about 1,200 feet in length.



VIEW OF DAM SITE AT THE BUTTES, GILA RIVER, LOOKING NORTH.

other and larger tunnel will be cut through the ridge to the east
dam, on a considerably steeper grade, and discharge on a level
the river bed, for use as a sluiceway in clearing the reservoir of
ent. The discharge of the Gila River was measured by the
d States Irrigation Survey for the year ending August 31, 1890.

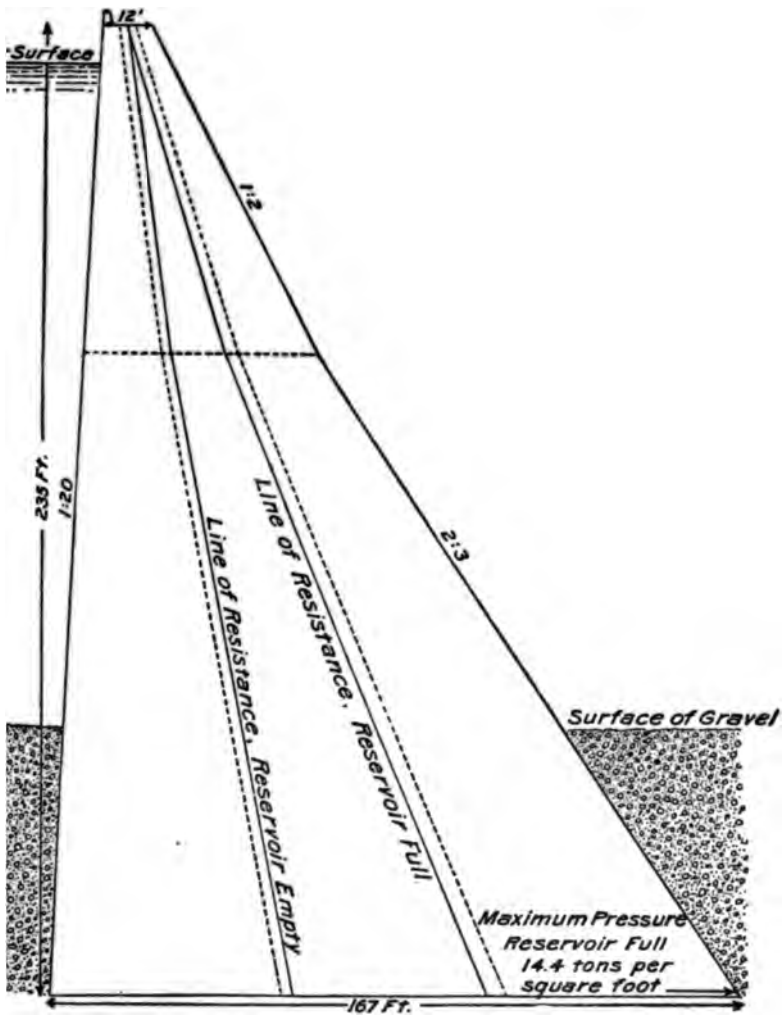


FIG. 13.—Profile of proposed dam at The Buttes.

results of this measurement are given on page 40. Measure-
s for irrigation investigation, under the auspices of the Indian
au, were begun by the writer at the same point December 10,
and continued until July 1, 1896, and they have been continued
that date to the present time by the United States Geological
ey. Previous to this private parties endeavoring to establish

claim to this reservoir site took readings of gauge height and occasionally measured the velocity by the use of floats. With the data obtained in this manner, and by comparison with measurements made in 1896, the discharge of the river has been approximated from July to December. The results for 1895–96 are given on page 40, and a diagram of the discharge as actually measured is given in fig. 7. The area of this basin is so large, its topography so varied, the rainfall so small and erratic, and the evaporation so great that it is impossible to arrive at any conclusion from theoretical considerations as to the amount of run-off to be expected from it. This can be determined only by a long series of measurements. It is probable, however, that an area of 75,000 to 100,000 acres can be reclaimed by waters stored at this point. The cost of such reclamation would be something over $2,000,000.

QUEEN CREEK RESERVOIR SITE.

Queen Creek rises in the mountains to the eastward of Silver King mine, and, flowing in a general southwestern direction, leaves the mountains below Whitlow's ranch, and in ordinary years loses itself in the desert north of the Gila River Reservation. In times of extremely high and protracted floods the waters of this creek reach Gila River several miles below Sacaton Agency. At Whitlow's ranch the creek passes between two buttes, forming a narrow rocky gorge advantageously conditioned for a dam site, and above this point the valley spreads out in a broad basin favorable for storage. This project was investigated in 1896 in connection with the irrigation investigation[1] for the benefit of the Pima Indians on the Gila River Reservation, little being known of its possibilities when the field work began. A topographic map of the drainage basin was made on a scale of 1 mile to an inch, with contour intervals of 100 feet. Its area is 142.5 square miles, or 91,200 acres, 61 per cent of which lies above the elevation curve of 3,000 feet and 39 per cent below that curve. The reservoir site was surveyed on a scale of 5 inches to the mile, curves of 10 feet interval being inserted to an elevation of 140 feet above the bed of the creek at the dam site, which is topographically the limiting height of a possible dam at this site. The practical limit, however, is reached at an elevation considerably lower, owing to the meager water supply, which is limited by the small drainage area, the aridity of the climate, and the great evaporation to which the impounded waters would be exposed. The plans proposed provide for a dam 115 feet above the bed of the creek. It is to be built on the rock-filled plan, with a water slope of 1 in 1, a down-stream slope of 1 in 2, and a top width of 10 feet. (Fig. 14.) Upon the water slope is to be laid a sheathing of asphalt concrete, and from the up-stream toe an impervious wall of cement rubble masonry is to be

[1] See report in Senate Document 27, Fifty-fourth Congress, second session.

ELEVATION OF PROPOSED DAM AT THE BUTTES.

arried down to bed rock, which, in the deepest place, is about 30 feet. n outer shell of carefully laid dry rock wall is to be built, which ill be carried down to bed rock at the down-stream toe. Spillways ill be excavated at each end of the dam, and it is from these that ock will be obtained for the construction of the dam. Little is known f the hydrographic possibilities of this basin, owing to the almost otal absence of data on the subject. A record of rainfall ten months n duration was kept at Silver King, but its results appear to be of oubtful utility. Measurements of discharge were begun at Whit-

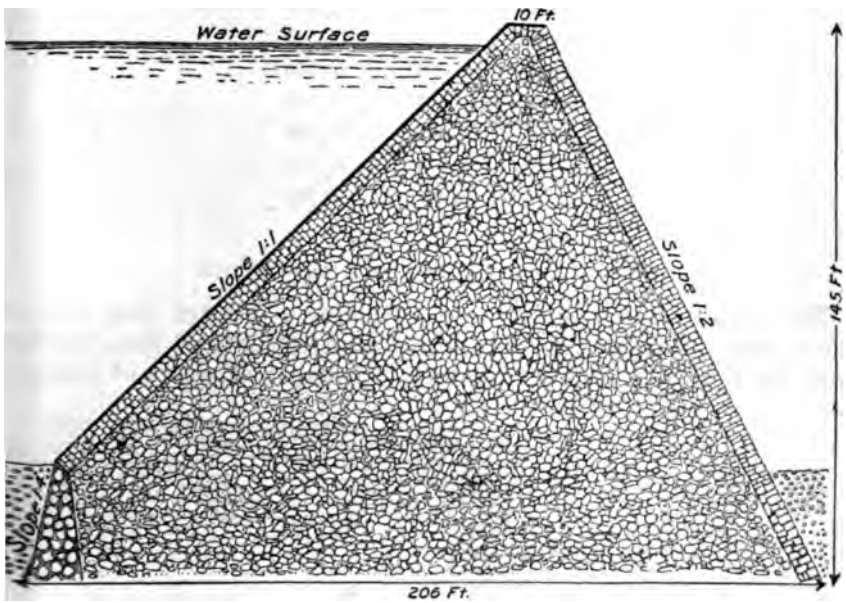


FIG. 14.—Profile of Queen Creek dam.

w's ranch in July, 1896. It is very difficult to make these measrements with any considerable degree of accuracy, owing to the xtremely flashy character of the stream. Almost the entire discharge t this point is in the form of violent floods. It is estimated that a upply of about 10,000 acre-feet per annum can be depended upon om this project, sufficient to reclaim about 5,000 acres of land at a ost somewhere about $200,000. A table and diagrams of discharge f this stream may be found on page 42. An abundance of excellent nd lies near at hand, with perfectly smooth surfaces and a maxium slope of about 40 feet to the mile.

Area and capacity of Queen Creek Reservoir.

Contour.	Area, in acres.	Capacity in acre-feet.
2,060	8	40
2,070	22	190
2,080	52	560
2,090	112	1,380
2,100	209	2,985
2,110	279	5,425
2,120	356	8,600
2,130	445	12,605
2,140	538	17,520
2,150	630	23,360
2,160	757	30,795
2,170	894	39,050
2,180	1,019	48,615
2,190	1,191	59,665

THE LOWER GILA STORAGE RESERVOIR.

This project contemplates the construction of a large dam on the Lower Gila in the gorge below Oatman and Cottonwood flats, not far from the railroad station of Sentinel. So great diversity of climate

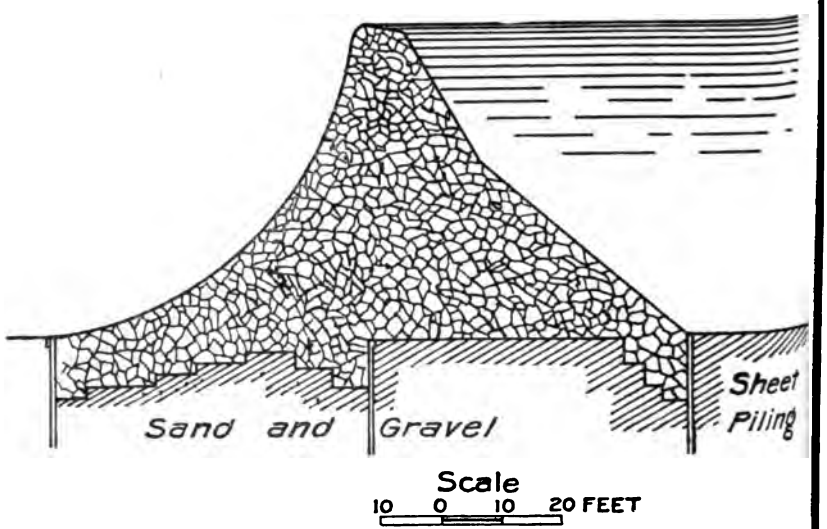
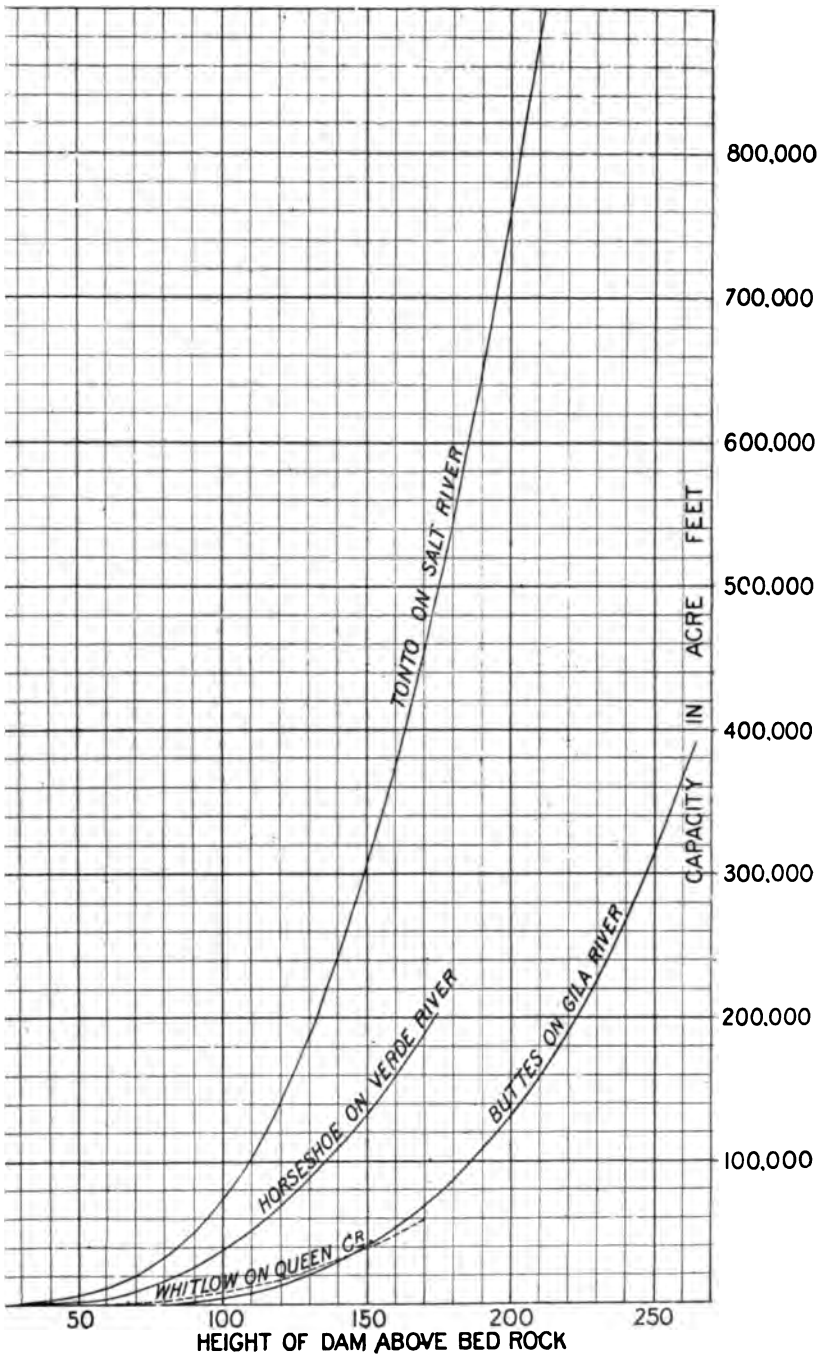


FIG. 15.—Section of proposed South Gila dam.

and topography is embraced by the drainage tributary to this reservoir that it is likely that it would receive a large run-off available for storage for irrigation and very materially increase the area reclaimable *after all* reservoirs in the upper portion of the basin are utilized.



)MPARATIVE DIAGRAM OF RESERVOIR SITES, GIVING CAPACITY OF EACH FOR VARIOUS HEIGHTS OF DAM.

n this reservoir was begun in 1892, but was discontinued, inancial difficulties, in the year 1893. It is the plan at pres- struct at this point a dam 50 feet in height, a section of hown in Fig. 15. It is to be an overflow dam, protected on ı with asphalt concrete. Seepage under the dam is to be far as possible, by three rows of fluted sheet piling, one row , one at the axis, and one at the heel of the dam. This dam ilized also as a diversion dam to raise the waters into the canal, which will be taken out about 30 feet above the nat- of the river, leaving 20 feet storage capacity above the bot- canal. The amount of this storage capacity is not known, loubtedly great.

FUTURE DEVELOPMENTS.

development of irrigation in Arizona by the simple diver- ıter from the Gila River and its tributaries is impossible. y indicated, the dry-weather flow of these streams is over- ted. The area irrigated from such streams can be increased conomical use of the water now claimed, but the actual water r irrigation can be increased only by storage and in some the development of underground sources.

NATURAL ADVANTAGES.

t extent of land in southern Arizona of surpassing fertility, situated for irrigation, and with a climate the aridity and f which make it at once exceptionally healthy and marvel- luctive, and depending for its development and reclamation n the practicable water supply, renders the item of water vital importance to the future history of the Commonwealth. ssible in the present state of knowledge regarding this ques- ke even an approximate computation of the extent to which supply can be increased. Enough is known, however, to ummary of the known possibilities considerable interest and ntific value. Unquestionably the main reliance for the n water supply is the storage of storm and winter waters and he season of melting snows, to be held and allowed to flow and only as needed, instead of flowing to the sea, or of being r a short time in excess only to evaporate.

STORAGE OF FLOODS.

respects the topographic and climatic conditions in Arizona arly favorable for the complete utilization of its hydrographic es. Few sections of the country are so well supplied with reservoir sites favorably situated for the conservation of the aters well above the areas to be irrigated. These favorable

conditions seem to apply not only to the location and great ca of the reservoir sites, but to their engineering practicability.

This is a point the importance of which is realized by few p who have not made irrigation engineering a specialty. The i sion seems to be well-nigh universal that wherever a locality i vided by nature with surplus waters that are discharged in to and wasted, such waters can be stored and entirely utilized for i tion. As a matter of fact, the truth of this proposition is the exc rather than the rule. This is chiefly due to the scarcity of pract topographic conditions for the construction of reservoirs at the where needed. The storage of water for domestic use in cities is accomplished where natural conditions are by no means favo because water for this purpose is far more valuable than it is likely to be in any part of the world for general irrigation pur While it may be practicable and economical in some cases for to pay tens or even hundreds of dollars per acre-foot for wat domestic use, any such price is absolutely prohibitory where the is intended for irrigation on a large scale, even in those parts world where irrigation is brought to greatest perfection, where ucts are of the most exceptional nature and highest value, and commands the maximum price. But even in the case of city sup it is by no means practicable in all cases to construct storage voirs at the required height within practical limits of expense.

It will thus be seen that for the storage of water for irrigati existence of peculiar and favorable topographic and geologic tions for the construction of reservoirs is of no less importanc the existence of waters to be stored. A basin of large capacity, c of being closed by a structure of small dimensions and unquesti safety, or if naturally already inclosed, capable of being pierce tunnel or cut for drawing off its waters, must exist at an ele sufficiently low and in a locality convenient for the reception waters to be stored, and sufficiently elevated and convenient f waters to be carried, within practicable limits of cost, upon the to be irrigated. Such reservoirs, furthermore, must be of consid depth; otherwise the great bulk of the stored waters will be l evaporation before they can be utilized. This is peculiarly t Arizona, on account of the excessive aridity and heat of its cl Even with the most favorably conditioned storage sites this i evaporation always curtails the efficiency of a reservoir site and a limit upon its utility for the purposes intended. The less the of the water impounded the more favorable must be those topog conditions, but for any purposes of irrigation they must be so able as almost to be topographic curiosities, and such are of com tively rare occurrence.

Another element of error in the popular assumption above ref to arises from the fact that the great floods which bear such imm

antities of water running to waste and which make such a strong pression on the public mind are so infrequent in occurrence and so ormous in volume that their storage and complete utilization are ipossible. The observation of these great floods, such as those of 91, in both the Salt and the Gila rivers, produces an impression upon e popular mind that the possibilities of irrigation by storage are stly larger than in fact they really are. Even assuming ideal contions regarding the existence and location of feasible reservoir sites, e are forced by a study of the facts to the reluctant conclusion that ch great floods bear no relation to the extension of irrigation by eans of storage except to imperil the works. As before stated, these eat floods occur only once or twice in a great many years, and irrigaon can be extended only in approximate proportion to the supply of ater that can be obtained in the driest years. To a certain extent y years may be reenforced by the conservation of the waters from ars of excessive run-off. Of course, the reservation of a large surus over and above that required for irrigation in the year of great n-off requires the provision of extensive storage capacity and conquent increase in the cost of the works, but a limit to the utility this method is quickly reached, especially in the climate of Arizona, the heat and aridity there prevalent.

The potential evaporation is equivalent to a depth of nearly 8 feet this region, and a reservoir in which the reserve storage filled it ly to a depth of 8 feet would be entirely evaporated before the next ason. If the reserve storage extended to a depth of 16 feet, it would all lost before the second year was reached. To tide over a series dry years a reservoir of great depth is necessary. When we conder the fact that all storage reservoirs which it is practicable to onstruct for purposes of irrigation have their greatest areas in the pper contours, it will be seen that to subtract 8, 16, 32, or 40 feet rom the upper zones of such a reservoir is to lose an enormous proortion of its stored contents. For instance, in the areas and capacties of the reservoir surveyed at The Buttes, given on page 72, we nd that for a depth of 150 feet the area of the reservoir is 3,149 acres nd its capacity 174,000 acre-feet. Should it be attempted to hold uch a reservoir filled with water for a period of say four years, we hould have an evaporation of at least 30 feet from its surface, which ould lower it to the 120-foot contour, at which the capacity is 97,000 cre-feet, or a little more than one-half the quantity which was held s a reserve. Should it be desired to hold a depth of 100 feet in the eservoir as a reserve for use in dry seasons, we find that in a period f four years, assuming the evaporation in that time to be 30 feet, the mount would be reduced from 61,355 acre-feet to 24,545 acre-feet, a ss of about 60 per cent. If the depth of reserve storage were adopted 70 feet, we should have a capacity of 24,545 acre-feet, which would reduced by four years' evaporation to about 5,000 acre-feet, or

about 21 per cent, and another year would practically exhaust it. In the Sweetwater Reservoir, in southern California, 90 feet in depth, 80 per cent of the capacity of the reservoir is within the upper 30 feet of height and 40 per cent within the upper 10 feet.

It will be readily seen that the practical utility of a reserve storage is limited to three or four years, even with very deep reservoirs. With comparatively shallow reservoirs no such use is possible. Such great floods as occur only once or twice in ten or twenty years can not be held, even with unlimited storage capacity, to reenforce the years of minimum run-off, which of course occur at essentially similar intervals, and the meager observations at hand seem to indicate that they are not needed in the years in which they occur, as such years are likely to yield more than the average quantity of run-off, independent of such floods. On the other hand, they are a constant menace and a positive peril to the stability and perpetuity of the reservoir, owing both to their great magnitude and the great difficulty of determining what this magnitude is. Enormous and very expensive facilities must be provided for carrying them out of the reservoir without injury to the dam.

SILTING OF RESERVOIRS.

One of the most difficult problems presented in the storage of these great torrents is the enormous quantities of rocks, gravel, sand, mud, and silt which they carry into the reservoir, and even though no part of the flood may be held, the load of solid material is deposited and contributes to fill it and destroy its storage capacity. These terrible torrents, useless and dangerous as they are, contribute the major portion of the solid matter which is caught by such reservoirs, and this is one of the most serious and difficult problems to be solved by the irrigation engineers in southern Arizona. The amount of solid material brought down in this manner can be learned only by impounding and measuring it. Measurements of matter carried in suspension have been made on the Mississippi, on the Potomac, on the Rio Grande, and on streams in California, but even if these streams could be shown to bear any fixed relation to the torrents which it is proposed to control in Arizona the problem would still be unsolved, as an unknown quantity of such material is rolled along the bottom. This is proved by the large numbers of bowlders, small rocks, and gravel they carry which never could be held in suspension. Careful surveys have been made of new reservoirs in California with this problem in view, and after a lapse of several years a resurvey will doubtless furnish valuable information, but this is not available at the present time. The amount of solid material carried by the torrents of southern Arizona can be learned only by impounding it. As it is considerable, it is obvious that a reservoir built on such a water course will eventually fill with solid matter unless means are provided for its removal. No entirely efficient plan for this purpose has ever been put in operation.

It is usually assumed, and often with truth, that the life of the reservoir is sufficiently long to justify its construction, even though it will eventually fill and have its usefulness destroyed. The amount of material carried by streams in southern Arizona, especially in the summer floods, is too large and the necessity of the reservoir to the life of the district to be irrigated from it is too vital to justify this convenient solution, or rather evasion, of the problem.

At least one eminent engineering authority has expressed an opinion that such a reservoir, even when filled, would retain about 30 per cent of its available storage capacity in the voids of the material deposited. It would seem, however, that this opinion is entirely without foundation. The fluctuating character of such streams, as well as the widely variant specific gravity of the material carried, insures such a mixture of materials in regard to their fineness that the proportion of voids would be much smaller than in a body of sand or other material of approximate uniformity of size. By filling any given volume with coarse materials, such as bowlders, filling the voids of these bowlders with coarse gravel, these voids again with finer gravel, and so on through the coarser grades of sand to the very finest silt, using of each material just enough to fill the larger voids in the coarser material, a mass will be produced with an extremely small percentage of voids. This is roughly the course pursued in the manufacture of concrete, and apparently would be approximated by nature in the case of a mountain reservoir. But whatever the percentage of voids, the water contained therein would not only be held strongly by the forces of capillary attraction and surface tension, but the friction in the containing material would resist its escape so powerfully that even that portion which could be drawn off would escape with extreme slowness. While probably such a reservoir might store and yield for use a considerable quantity of water, it is clear that this quantity could not aggregate anything like 30 per cent of the original capacity of the reservoir.

It has been proposed to sluice out such material by providing large openings from the reservoir and occasionally allowing a large volume of water to rush out and carry the collected material with it. This method has been successfully employed in diverting dams for keeping open the approaches to the head gates of canals. It is also extensively employed in cleansing reservoirs in Spain. But experience has shown that only a comparatively small area is cleaned by this method, reaching on a steep grade for a moderate distance above the scouring sluices. For clearing a reservoir several miles long it is manifestly inadequate and must be supplemented by something else.

Another method of counteracting the tendency of the reservoir to fill is by enlarging its capacity. This method is not always possible. Where possible it is always expensive, and so far from being a solution of the problem, merely postpones the date when some means

must be adopted of clearing out the impounded silt. It may, however, in some cases be advisable, where the expense is not too great, as the combined effect of raising the dam higher and of its filling with silt is to increase the altitude of the surface of the silt above the scouring sluices, and, by increasing the velocity of the water which is used in sluicing out the silt, to increase the efficiency of that means of cleansing the reservoir.

The removal of the accumulated débris by the ordinary methods of excavation is clearly out of the question. No community in the world can afford to pay for an acre-foot of storage capacity for the purposes of irrigation any sum approaching the cost of an acre-foot of excavation by the ordinary methods. A method is here suggested, however, which it is believed might be applied in many cases, and when properly adapted to the topography and hydrography of the locality, would, it is believed, be effective in some cases within practicable limits of expense. The method proposed is as follows:

A small water supply is to be obtained at considerable head over the reservoir site, either by diverting the stream at a distance above the reservoir or by storing waters in a small reservoir on the stream or some of its tributaries and carrying them in pipes or flumes above the upper edge of the reservoir to the vicinity of the dam. At points along the side of the reservoir which are topographically favorable, preferably upon ridges jutting out into the lake, hydraulic giants are to be provided, to act under the head of water furnished by the pipe line. Large sluiceways are to be provided near the dam, and at such times as the reservoir happens to be empty these sluiceways are to be opened to their full capacity and the deposited material hydraulicked out, as in hydraulic mining. The material, being mostly fine and freshly deposited, would wash easily and rapidly and be carried by the stream out of the reservoir through the sluice gates. This water need not be wasted, but could be diverted below for purposes of irrigation. It is not denied that such works and such methods would be expensive, but, on the other hand, their effectiveness is unquestionable, and it is believed to be by far the most feasible method yet proposed for cleaning out a large reservoir. The tendency of an economical use of this method would be to keep the reservoir open in its lower part, where it is deepest, and allow the shallow portions along the edges and at the upper end to remain filled. This would contract the relative area of water surface and diminish evaporation, which would in a measure compensate for the destruction of storage capacity.

The use of the three methods, first, the employment of one or more large scouring sluices, after the manner of the old Spanish reservoirs; second, the enlargement of the reservoir to the practicable limit; and, third, the construction of works and the adoption of operations like those above described, would in many cases insure the perpetuity of

storage reservoirs in this country within practicable limits of expense. Certain it is that some efficient method or methods for this purpose must be employed or the extension of irrigation in any great degree in southern Arizona by means of storage is impossible.

The problem just discussed suggests the advisability, where feasible, of constructing storage reservoirs in side canyons or other basins having no considerable natural drainage tributary to them, the water being carried through artificial conduits from the streams whose waters it is desired to store. Where this can be done the danger of filling the reservoir with silt can be easily averted. Sand boxes can be constructed along a conduit and easily operated in such manner as to effectually clear the waters of their load of solid matter.

Aside from the scarcity of natural sites of this character, their efficiency is limited by a fact more strongly emphasized in this than in most countries, that the surplus waters are discharged in sudden floods of enormous volume, and in order to impound them or any considerable percentage of them by this method, not only must strong diversion works be provided for diverting them, but a conduit must be constructed of enormous capacity. If this conduit must be of considerable length or in very rough country—and both conditions usually obtain—the project is defeated by that great bugbear of irrigation possibilities previously referred to—the cost.

In respect to the existence of good natural reservoir sites upon streams carrying the bulk of its surplus waters, southern Arizona is particularly fortunate. The information upon this point, however, far from complete, and the subject deserves careful expert investigation.

EVAPORATION.

As previously suggested, one of the most serious obstacles to the extension of irrigation in Arizona by means of storage is the high rate of evaporation, which often exceeds 100 inches in depth in a single year.

A compilation of evaporation results acquired by the Irrigation Survey is given in the Eleventh Annual Report of the Geological Survey, Part II, Irrigation, page 34.

It has been proposed to lessen evaporation from reservoirs by the cultivation of aquatic plants, whose leaves are intended to cover the surface and partially shade the water. This plan was suggested by Captain Glassford in Irrigation and Water Storage in the Arid Regions, page 307.[1] It is hardly probable that this method can be very effective, from the fact that such part of the leaves as are above water will probably transpire more or less moisture themselves, and such parts as are covered with a film of water of course can not check

[1] Fifty-first Congress, second session, Ex. Doc. No. 287, Irrigation and Water Storage in the Arid Regions, a report on the climatology of the arid regions of the United States with reference to irrigation. By Gen. A. W. Greely.

evaporation in any degree. A test of a similar method of checking evaporation was made by Prof. Edward M. Boggs, irrigation engineer and meteorologist of the Arizona Agricultural Experiment Station, the result of which is given by him in Bulletin No. 20, on Arizona Weather, page 7:

> A second tank, an exact duplicate of the first, placed by its side, and provided with a similar gauge, was planted with water lilies of the genus *Nymphæ*. Measurements were commenced in this tank in September, 1892, when the leaves well covered the surface of the water. They were continued until April, 1894, when the gauge was needed for another use. A comparison of the results is shown by parallel columns in Table IV. It will be seen that the monthly totals of the two tanks are in substantial agreement. The differences are usually small. The excess changes so often from one tank to the other as to lead to the conclusion that differences are due to accumulations of errors incident to observation. But it is not easy to apply this explanation to the difference of 0.75 inch in favor of the lily tank occurring in June, 1893. However, the idea that the leaf covering has diminished the evaporation to any considerable extent is dispelled by the fact that for the eighteen months of the record the difference amounts to 1.52 inches only, a divergence of about 1 per cent.

Another device is here proposed which may be worthy of consideration, and which it is hoped may receive tests similar to those conducted by Professor Boggs. It is proposed to cover the surface of the reservoir with a film of crude petroleum, which will form a more or less coherent sheet of gum upon the surface and prevent the contact of air with the water as long as the surface of the reservoir is still and placid. The tendency of oil to diminish motion of water in waves and riffles is well known, and this project might prove more or less effective at such times as the winds are not too violent or constant. This suggestion is made for what it is worth, in the hope of inducing experiments to test its value. It must be admitted, however, that the prospect is meager for materially reducing the ravages of evaporation from reservoirs in this climate, and all plans and estimates should take them into account to the fullest extent.

MOUNTAIN RESERVOIRS.

It is eminently advisable in such a climate as that of Arizona to store waters for irrigation as far as practicable near their source, in order to obviate the enormous loss through evaporation when flowing for long distances through the sandy beds of streams.

It is often erroneously assumed that the run-off of a district is nearly proportioned to its area. In this arid region the mean discharge of the large streams is, owing to evaporation, often more nearly in inverse proportion to their catchment areas. Thus the Gila River at Yuma has a smaller discharge than at the mouth of Salt River, where its catchment area is far less. The Santa Cruz River, at the point where it leaves the mountains, discharges annually large quanti*ties of water,* which become progressively less, until well out into the

lesert the river is practically lost, and its discharge is zero. The ame is true in a greater or less degree of nearly all the important lrainage lines in the southern part of the entire arid region. Added o this is the fact that in the low, hot deserts the evaporation is usually o great as to make very serious ravages into the stored volume of ater after the rains have ceased, thus materially reducing the sup- ly available for irrigation.

The waters from a reservoir situated within a broad valley or open ountry must usually be conducted in broad channels constructed on ght grades through sand or loam where the loss from seepage and vaporation will approximate a maximum; while from a mountain eservoir it is usually possible to give delivery canals heavy grades nd high velocities, reducing seepage and evaporation to a minimum; nd, with plenty of grade to spare, natural drainage lines may be tilized to a great extent. The seepage from high-level canals ften reappears at lower levels and is not entirely lost. Further- iore, water stored in the mountains may usually be made to furnish large amount of power that will in the future be very valuable, ithout in the least affecting its availability for irrigation. It may e laid down as an almost general rule that where there is a choice ; is far better for the future of the arid region that water be stored 1 or near the mountains than on desert plains, even when the cost f such mountain storage is much greater than the same capacity at ower levels.

The reservoir sites already described on New River, Rio Verde, Hila and Salt rivers, Hassayampa, Queen, and Cave creeks, which re contemplated in the plans of existing companies, are doubtless he best that can be utilized on those streams, and are usually s great and in some cases greater in capacity than required for the conomical conservation of the waters yielded by the drainage area ributary to them, exclusive of the great unusual floods which, as reviously pointed out, it is neither practicable nor desirable to mpound. On the drainage of the Gila proper, however, it is not mprobable that undiscovered reservoirs exist in the mountains near he head waters of the Santa Cruz, San Pedro, San Francisco, and Gila vers; Eagle, San Carlos, and Blue creeks, and other tributaries in he mountainous regions, where waters can be more economically ored than at The Buttes. When all such reservoirs are constructed nd fully utilized, and the ordinary spring and summer flow of the ver entirely diverted for irrigation in the neighborhood of Solomon- ille and Fort Thomas, the reservoir at The Buttes may be relied pon to impound the balance of the run-off tributary to its drainage, ith the exception of the unusual floods referred to. This reservoir admirably located for the purposes above outlined, being of large apacity and, situated at the point where the river finally leaves the ountainous region, intercepting nearly all the mountain drainage

yielding the largest percentage of run-off, and yet of sufficient elevation to command all the irrigable land adjacent to the middle and lower portions of the river.

When all such sites are utilized there will still be a large area of excellent unwatered lands in the valleys of Arizona and a large amount of surplus flood waters, which, for reasons outlined on page 79, it is not practicable to store in the reservoirs in the mountains. Though these reservoirs include in their catchment the greater portion of the best drainage area of this basin, large areas of foothills, plains, and rocky ridges will still remain which are subject to occasional cloudbursts and yield in the aggregate a large run-off. A part of such waters, as well as such part of the seepage from canals and irrigated fields as finds its way back into the stream, can be impounded by the construction of a large reservoir on the lower Gila, as described on page 76. Whether it would be sufficient to utilize the water available for storage after the upper sites in this basin have been brought into use can not, of course, be known at present. Certain it is that no rights to flood waters should be acquired by such a reservoir to the prejudice of those in the mountain regions, where the water can be so much more economically impounded and applied, and in the absence of laws controlling this matter it is not to be regretted, but is rather a subject for congratulation, that this project has not been carried to completion; and it is to be hoped, for the sake of the future of irrigation in Arizona, that it will not again be revived until at least the best of the reservoir sites hereinbefore described have been constructed or some legal provision has been made to secure their full utilization.

UNDERGROUND WATERS.

The possibilities of irrigation by the development of percolating waters deserves mention. There is in Salt River Valley at present a large quantity of water in the gravels underlying the valley. The well employed to furnish the greater part of the domestic supply of water for the city of Phœnix is 35 feet in depth and 8 feet in diameter. It normally contains a depth of 18 feet of water. The walls are of cement, so that water can enter only at the bottom. Two Dean pumps, each of 840 gallons per minute capacity, are used to raise the water into the stand pipe. Both pumps usually run at nearly full capacity in July and August, and have raised 33,000,000 gallons per month. The discharge has sometimes exceeded 1,400 gallons per minute, which would lower the water in the well about 6 feet, but when the pumps are stopped the water recovers its level in a few minutes. A well was dug into the gravel in the vicinity of Mesa, and a centrifugal pump of about 1,200 gallons per minute capacity was used to keep the water down and permit the progress of the work. The

ess of water became so great as to be beyond the capacity of the ap, and work was stopped for that reason.

his large quantity of underground water is doubtless due to the essive application of water, as previously described in this report, ough the months of April and May, while the water in Salt River bundant, and irrigators are attempting to "soak up" the land paratory to the low-water season, when the competition for water ats becomes severe. If in future this excessive supply during the ng months is stored in great reservoirs, as is proposed by the jects now contemplated, the "underflow" will be greatly reduced, ause so great an excess of water will no longer be applied to the ls. Some water will always escape from the fields into the subsoil, canals and ditches will also lose a portion of their supply by page, which will be caught by the underflow. This source of sup- , while for these reasons somewhat uncertain at present, is impor- t in the future development of the valley.

[easurements were made in the month of June, 1896, by Mr. Cyrus Babb, of Salt River above the head of the Arizona Canal, of the ount of water taken out by each canal, and the amount remaining he river below its head. These measurements proved that a con- erable quantity of water is returned by seepage to the river bed, ich was taken out for irrigation lower down. In one case the rease was 80 second-feet in 7 miles, as previously stated. Undoubt- y the amount lost by evaporation of these return waters from the er bed and the adjacent soils was much greater. While it is a tification to know that some part of the surplus waters applied to land returns to the river and can be used again, still this fact ords no excuse for such use, and should not be allowed to weigh in or of its continuance.

n some other parts of the Territory are found underground waters greater or less abundance, which may in some cases be profitably eloped by pumping or otherwise for irrigation purposes. This is e at least in the country which receives the lost waters of the Santa z and some other streams which have ordinarily little or no surface ications, but still discharge more or less water through a pervious soil. Water may be obtained in abundance a short distance eath the surface along the valley of the Gila River, in the Pima ervation.[1] Mr. Albert F. Colton has collected a quantity of data ting to wells in the Casa Grande Valley, some of which have quite nsiderable flow and vary in depth from 20 to 100 feet. In other ts of the Territory wells have been sunk to depths greatly exceed- 100 feet without striking water. The information collected by Geological Survey, together with that gathered by Mr. Colton, so

[1] rigation Investigation for Pima Reservation. Senate Doc. No. 27, Fifty-fourth Congress, d session.

far as relates to Maricopa and Pinal counties, is shown in the foll ing tables:

Wells of Pinal County.

No	Post-office.	Owner of well.	Location.			Year completed.	Diameter.	Depth of well.	Depth of water.	Cost of	
			T.	R.	S.					Well	
							Ft. in.	*Feet.*	*Feet.*		
1	Arizola	Geo. W. Sanders	6	6	22	1892	4 0	40	3	$100	
2	do	Peter H. Loss	6	7	19	1893	4 0	44	6	35	
3	do	H. J. Cleveland	6	7	19		0 6				
4	do	Fred Weaver	6		32	1896	4 0	52	2		
5	do	— Cooley	7	7	5	1895	4 0	53	3		
6	do	M. R. Mann	7	6		1894	3½ 0	54	2	54	
7	do	E. Hadley	6	6	34	1892	4 0	50	5		
8	Casa Grande	R. B. Dennis	6	6	20	1896	5 0	45	2		
9	do	Andrew Soundburg.	6	7	36		4 0	49	3		
10	do	L. S. English	6	5	23	1892	4 0	56	5		
11	do	F. G. Logan	6	6	32		0 6	75	30		
12	do	S. P. R. R.	6	6	29		8 0	56	8		
13	Dudleyville	George Scott	4		25	1885	4½ 0	14	2	5	
14	do	O. H. Swingle	6	16	20	1878	4 0	21	6	25	
15	Florence	A. T. Colton	5	9	35	1888	4 0	45	1	56	
16	do	Whitney	5	9	10	1891	4 0	70	2		
17	do	Christopher Salmon.	5	7	25	1890	3 0	30	2	40	
18	do	T. F. Marquand	5	7	13	1895	12 0	23	7½		
19	do	L. E. Graham	5	8	24	1891	6 0	56	6		
20	do	J. M. Hurley	5	9	32	1891	4 0	102	31		
21	do	James F. Pry	5	8	27	1896	3 8	39.3	1.7	10	
22	do	Wm. H. Graham	5	8	28	1893	4 0	32	4		
23	do	F. E. Carpenter	5	8	35		4 0				
24	do	— Morrell	5	8	26		3½ 0	44	4		
25	do	Daniel Bingham	5	8	26		4 0	51	2		
26	do	Shields & Price	5	8	24		3 0	66	5	66	
27	do	Peter R. Brady	4		34	1884	4 0	27	2	99	
28	do	Abandoned	3	10	35		10 0	100	0		
29	do	Thos. Buchanan	1	8		1885	0 5	232	24		
30	do	Whitlow Bros	2	10	1	1883	0 6	126	106	500	
31	do	R. H. Martin	3	10	5	1883	0 6	413	0	1,000	
32	do	Harrington	2	7		1892	3 4	160	5		
33	do	Lew Baley	2	10	14	1888	0 6	180	0		
34	do	Mexican	1	10	34	1882	0 4	58	0		
35	do	Barmodath	1	10		1883	0 4	158	0		
36	do	Bark & Creswel	1	10		1879	0 6	18	9		
37	Kenilworth	W. J. L. Baron	5	8	25	1892	4 0	65	5½	65	
38	Maricopa	S. P. R. R.	4	3	17	1885	16 0	34	5		
39	Sacaton	Wilson	6	5	24		4 0	42	2½		
40	do	W. J. Stulz	6	7	27	1895	3 0	52	3	50	
41	do	U. S. Indian agent	4	6			11 0	26½	8½		

Wells of Maricopa County.

No.	Post-office.	Owner of well.	Location.			Year completed.	Diameter.	Depth of well.	Depth of water.	Cost of—	
			T.	R.	S.					Well.	Machinery.
							Ft. in.	*Feet.*	*Feet.*		
42	Phoenix	E. F. Kellun	1	1	6	.....	0 7	554	.....	$5,000	.....
43	.....do	Frank A. Phillip	1	2	27	1892	14 0	20	14	300	$2,700
44	.....do	Phœnix Water-works.	1	3	5	1889	8 0	35	17	5,000	10,000
45	Tempe	C. G. Jones	1	4	13	1889	4½ 0	20	12	.....	.....
46	Mesa	Wm. Standage	1	5	20	1895	5 0	42	4	80	.....

No. 1.—Dug well; depth of water does not vary; it can not be easily lowered; flow has not minished; water, soft; raised by bucket and used for domestic purposes; elevation of surface, 412. Strata passed through: Sandy soil, 11.5 feet; volcanic ash, 3 feet; hard whitish rock, 2 et; sand and small gravel, 8.5 feet; wash gravel, 3 feet; hard whitish rock, 1 foot; gravel, 2 et; hard rock of a water-line formation, 9.5 feet.

No. 2.—Dug well; depth of water does not vary, nor is it easily lowered; flow remained stacionary; water rose 4 feet when struck; water, soft; raised by pump and used for domestic purposes; elevation of surface, 1,448 feet. Strata passed through: Clay soil, 6 feet; gravel, 8 feet; nd, 28 feet; rock of a water formation, 2 feet.

No. 3.—Bored well; elevation of surface, 1,452 feet.

No. 4.—Dug well; depth does not vary; is not easily lowered; quality of water, soft; raised by ucket and used for domestic purposes; elevation of surface, 1,458 feet. Strata passed through layish soil; last foot lime as water formation.

No. 5.—Dug well; depth does not vary during year; quality of water, soft; water raised by uckets and used for domestic purposes; elevation of surface, 1,460 feet. Strata passed rough: Same as No. 4.

No. 6.—Dug well; depth does not vary during year; is not easily lowered; quality of water, ft; raised by bucket and used for domestic purposes; elevation of surface, 1,450 feet. Strata ssed through: Clay, with streaks of gravel; bottom in sand.

No. 7.—Dug well; depth does not vary during year; is not easily lowered; quality of water, ard; water raised by buckets and used for domestic purposes; elevation of surface, 1,433 feet.

No. 8.—Dug well; water easily lowered; quality of water, soft; raised by buckets and used r domestic purposes; elevation of surface, 1,393 feet. Strata passed through: Clay soil, 12 feet; ment, 14 feet; sand, 12 feet; then clay to water.

No. 9.—Dug well; quality, soft; raised by bucket; used for house and stock; elevation of surce, 1,454 feet. Strata passed through: Sandy soil; bottom in sound rock.

No. 10.—Dug well; depth of water does not vary during year; is not easily lowered; flow has creased; quality of water, salt at first, hard now; raised by buckets and used for domestic rposes; elevation of surface, 1,375 feet. Strata passed through: Gravelly soil; water in gravel.

No. 11.—Bored well; depth of water does not vary during year; is not easily lowered; water, kaline; raised by windmill; elevation of surface, 1,405 feet.

No. 12.—Water not easily lowered; it rose when struck; flow increased; water, hard; raised by mp; flow, 10,000 gallons per hour; elevation of surface, 1,395 feet. Strata at bottom: White nd.

No. 13.—Dug well; depth varies with height of river; can not be easily lowered; quality, a little kaline; raised by pump; used for domestic purposes. Strata passed through: Alluvial soil, with nd at water level.

No. 14.—Dug well; depth does not vary during year; can not be easily lowered; water, hard; mped and used for domestic purposes. Clay strata passed through.

No. 15.—Dug well; depth at first, 33 feet; water at 31 feet; sunk 1.5 feet each year; present pth, 45 feet, and 1 foot water; is easily lowered; flow diminished; elevation of surface, 1,488 et. Sandy clay soil.

No. 16.—Dug well; depth varies during year; water, hard.

No. 17.—Dug well; depth does not vary; is not easily lowered; rose one-half foot when struck; ality, soft; used for house and stock; elevation of surface, 1,398 feet. Sandy soil; bottom in nd.

No. 18.—Dug well; depth does not vary during year; lowers about 3 feet and no more; raised gang pump and horsepower; flow, 6,000 gallons per hour; used for irrigation; elevation of rface, 1,380 feet. Sandy soil for 13 feet; 2.5 feet clay; then water in sand.

No. 19.—Dug well; commences to lower in November and rise in April; variation about 1 foot; not easily lowered; quality, soft; raised by horsepower; waters 120 head of stock; elevation of surface, 1,455 feet; gravelly soil; bottom in water formation.

No. 20.—Dug well; depth does not vary; is not easily lowered; quality, medium; raised by pump; used for domestic purposes; elevation of surface, 1,505 feet; usual water formation of rock at bottom.

No. 21.—Dug well; quality, soft; raised by bucket; used for domestic purposes; elevation of surface, 1,440 feet; sandy soil on top water rock.

No. 22.—Dug well; water rises last of June, falls in December; not easily lowered; quality, soft, but getting hard; raised by pump; waters 20 head of hogs, 70 head of stock, 120 trees; elevation of surface, 1,416 feet; soil, sand and clay, with strata of hardpan at bottom, blue clay; main stream comes in from southeast.

No. 23.—Quality, soft; elevation of surface, 1,441 feet; same rock bottom.

No. 24.—Dug well; quality, salt; elevation of surface, 1,439 feet; sandy soil; bottom below water lime.

No. 25.—Dug well; quality, soft; elevation of surface, 1,450 feet; sand strata.

No. 26.—Dug well; depth varies during year; not easily lowered; quality, hard; raised by steam pump; elevation of surface, 1,467 feet; at 3 feet struck coarse gravel, lasting 20 feet; bottom in water lime.

No. 27.—Dug well; cased with redwood; lowers in summer; easily lowered; quality, soft and pure; soil, 11 feet alluvium, balance quicksand.

No. 29.—Dug well; size, 4 feet at top, 6 feet at bottom; level lowers some in summer; quality, soft; raised by steam pump, 1,000 gallons in twenty-four hours; used for stock, garden, and traveling public; strata, clay, sand, and small gravel, bottom in coarse gravel.

No. 30.—Drilled well; depth does not vary; can not be lowered with horsepower pump; used for stock; strata, limestone.

No. 32.—Dug well; depth lowers in summer; raised by horsepower and barrel; can be pumped dry in five hours; used for stock and by the public.

No. 33.—Drilled well; dry; 3 miles southwest of Whitlow's ranch; between this well and Florence are three other dry wells, with depths of 150 feet each.

No. 34.—Well sunk in Queen Creek wash, 2¼ miles below Whitlow's ranch; no water found.

No. 36.—Well at Goldfield; more water in well in winter; can be easily lowered; raised by hand pump; used for stock.

No. 37.—Dug well; level rises in April, falls last of July; is easily lowered; flow has increased; quality, soft at first, now medium; raised by buckets, and waters 100 head of stock and 30 trees; elevation of surface, 1,465 feet; gravelly soil with streaks of limestone.

No. 38.—Dug well; not easily lowered; water soft; raised by steam pump; discharge, 10,000 gallons per hour; elevation of surface, 1,170 feet; gravelly soil.

No. 39.—Dug well; elevation of surface, 1,380 feet; bottom in gravel.

No. 40.—Dug well; depth does not vary during year; can be lowered by two buckets; water soft, raised by buckets, and used for domestic purposes; elevation of surface, 1,450 feet; sandy soil; water in a soft sandstone.

No. 41.—Dug well; capacity tested by 6-inch centrifugal pump giving one-tenth of a cubic foot per second, or 8,640 cubic feet per day; percolating area, 242 square feet, indicating a yield of 36 cubic feet per day for each square foot of surface. This surface is in a very hard clay, which has stood eight years without walling and still shows marks of the pick used in digging; water used for mill and domestic purposes; raised by steam pump.

No. 42.—Bored and drilled well; 18 feet to surface water; slight flow at 382 feet; not easily lowered; used for irrigation; alluvial soil 15 feet, hardpan 10 feet, alternate gravel beds 150 feet, sand, cement, etc.

No. 43.—Dug well; depth fluctuates about 30 inches during year; can not be easily lowered; quality, soft; raised by steam pump; discharge, 2 second-feet, and irrigates 320 acres.

No. 44.—Dug well; level not easily lowered; quality, hard; water raised by pumping; discharge, 2,500,000 gallons per day; supplies water to city of Phœnix; level steadily risen during past ten years; first 16 feet alluvial soil, balance bowlders and coarse gravel.

No. 45.—Dug well; cased for 6 feet; level varies 4 feet during year; can be easily lowered; quality, soft; raised with bucket, and used for domestic purposes; strata, soil for about 14 feet, hardpan of cement and rocks, gravel.

No. 46.—Dug well; walled with brick; depth varies during year; not easily lowered; quality, soft.

A scientific investigation of further possibilities is very important, both to develop resources along this line and to obviate further loss from unsuccessful attempts of this character. The irrigation possibilities from underground development are undoubtedly important, but it is not intended here to emphasize this fact, for the popu-

ır mind is already filled with very exaggerated ideas of such possi-
ilities. Extravagant estimates of the quantity of "underflow" are
ife on all hands, and it is recognized as an important though thank-
ess duty to disabuse the public mind of such erroneous ideas so far
s possible. One phase of this general impression is the opinion that
he dry streams which abound in the valleys of Arizona must have a
ırge underflow because the same streams carry considerable water
arther up in the mountains. It seems to be forgotten that the poten-
ial evaporation in the valleys of Arizona ranges, according to locality
nd season, from 5 to 10 feet in depth on the entire area exposed to
uch evaporation.

It is the common assumption that evaporation is much higher from
water surface than from a saturated soil. The actual data on this
oint are very meager, but so far as observations have been taken
ıey seem to indicate that evaporation is greater from saturated sands
ıan from the surface of a deep body of water, even though such
ınds may appear dry on the surface. The reason for this may be
ound in the fact that the temperature of such sands rises much
igher under the action of the sun than that of a large body of water;
so, that for a considerable distance below the surface the particles
sand or of soil are kept moist by the action of surface tension and
ıpillarity for a considerable distance above the point where all the
oids in the sand are filled with water. By this means a far greater
ea of moist surface is exposed to the action of the dry air than is
ıe case with a smooth sheet of water.

But whatever the reason, and whatever the exact ratio the evapo-
ıtion from a sand bed bears to that of a body of water, we do know
ıat it is very great, and that if the precipitation of the entire Terri-
ory of Arizona were so distributed as to give the potential evapora-
on of the climate full play, the evaporation would, even in the very
ettest years, absorb the entire rainfall, and the run-off would at all
mes be absolutely zero. That the streams do yield a considerable
ıantity of run-off in the aggregate is due to the fact that precipita-
on is largely in excess of evaporation at certain times and in certain
aces, while at other times and in other places no moisture at all is
posed to the evaporating influence.

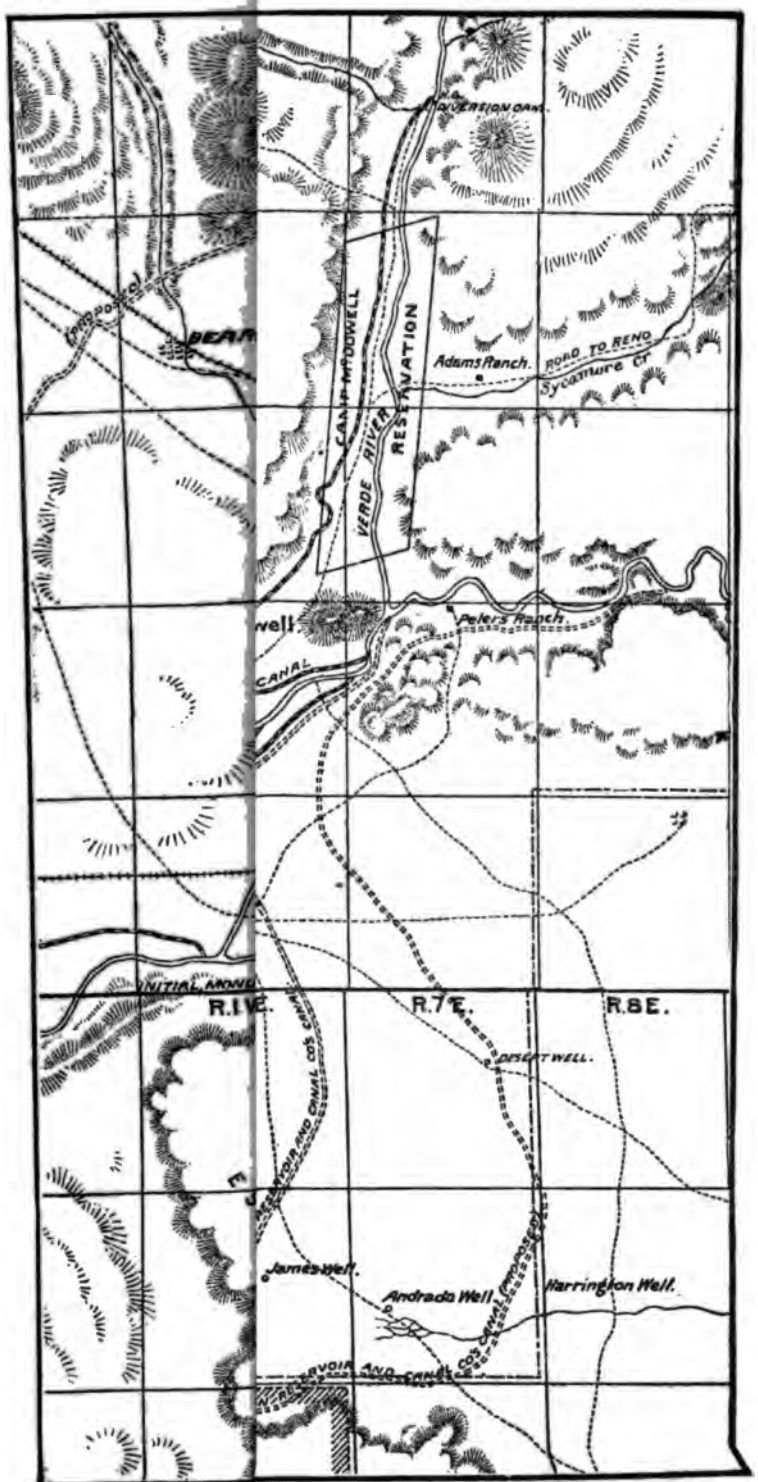
The above-recited facts are abundantly sufficient to account for the
ıenomena of many streams having a considerable discharge near
eir source in mountain regions and being ordinarily dry in valley
gions, by the evaporation of the water from their sandy beds, with-
t introducing the hypothesis of a large underflow. The Agua Fria
a typical stream in point. There are parts of its upper course in
ıich it is ordinarily a very considerable stream and is never dry;
ar its mouth it is ordinarily entirely dry and carries water only
seasons of excessive rainfall. The idea seems to have been at
e time prevalent that this stream carried a large amount of the

so-called "underflow," but the construction of the dam of the Agua Fria Water and Land Company, a short distance below Frog Tanks, which was carried down 40 feet through the sands to bed rock, made little or no perceptible increase in the permanent volume of water flowing at that point. A measurement was made of the water flowing through the sluiceway of the dam in April, 1896, and this showed a discharge of only 3.75 cubic feet per second, which is said to have been about the ordinary flow previous to the construction of the dam. Another measurement made the same day about a mile above this point showed a discharge of about 3 cubic feet per second. The difference between these measurements may perhaps indicate the increase in the stream due to the development of the underflow, though even this is by no means certain. Even if the entire discharge of the stream were considered as developed from the underflow, its volume is nowhere near commensurate with the cost of development. While the experience in this case is of course not conclusive with respect to all other streams, it is an emphatic refutation of the popular theory that such water as falls in rain must be found either flowing in the surface streams or underground. Attempts at extensive underground development should in all cases be preceded either by careful and judicious experiments or thorough scientific investigation.

The development of underground waters by means of pumps is greatly hampered by the scarcity and cost of suitable power. In some parts of the Territory firewood is at present abundant and cheap, but it is of slow growth, and if extensively employed in irrigation would in time become exhausted. The price of coal is prohibitory for any such purpose on a large scale in any part of the Territory, as is also that of petroleum, gasoline, or any other importable fuel. The time may come when some of the many available water powers in the foothills will be harnessed for the generation of electricity, to be transmitted to proper points and used for pumping water for irrigation, but these schemes can hardly be considered at present within the realm of practical consideration. A few attempts have been made to harness the winds to this work, but this motive power, always fickle and unreliable, seems to be especially so in these valleys; long periods of calm are said to occur during the months when water is most needed, and it is usually considered necessary to reenforce such plants with steam or other motive power. Some development, however, may be expected from nearly all the methods above mentioned, but for a long time to come they must necessarily be on a small scale and usually for individual purposes.

SUMMARY.

It may be in order here to point out some of the difficulties under which irrigation has heretofore labored, and to suggest means for obviating them in future. A glance at the map of Salt River Valley


DIVERSION DAM
CAMP McDOWELL
VERDE RIVER RESERVATION
Adams Ranch
ROAD TO RENO
Sycamore Cr.
Peter's Ranch
CANAL
INITIAL MONU
R.1 E.
R.7 E.
R.8 E.
DESERT WELL.
James Well.
Andrada Well
Harrington Well.

XX) will show at once that there has been an enormous waste ergy in the construction of numerous and parallel canals with cting claims and interests. On the north side of the river are armers', Salt River, Maricopa, Grand, and Arizona canals, to be leled by the partly constructed Rio Verde Canal. All of the land · the Arizona Canal could be watered much more cheaply and far greater economy of water from the Arizona Canal and its lat-

Most of the labor and capital expended in the construction of hers has been worse than wasted. So long as they are used in etition with a larger canal, acrimonious contests over water rights ıe inevitable result, and when all concentrate under one manage- the competition for water rights is transferred from companies lividuals, and as long as the smaller canals remain in use they fruitful source of waste of valuable water. On the south side e river the condition is, if possible, still worse. The Broadway San Francisco ditches, and Tempe, Utah, Mesa, and Highland s will be paralleled by a higher canal proposed by the Hudson voir and Canal Company. They might be advantageously super- by a single large, high-line canal, which would be far more mical of water, and all the labor and expense of the smaller s would thereby be obviated. The greatest evil of the system, ther lack of system, heretofore followed in the development of ıtion along Salt River, however, is the growth of conflicting claims ter. This has always been productive of vindictive and expen- itigation. Large areas of land have been brought under cultiva- having no adequate water right, and crops have been dried up labor wasted, and some areas abandoned, for lack of water for ıtion. This evil in this particular valley, so far as present condi- are concerned, may perhaps be largely remedied by the con- tion of storage works upon the Verde and Salt rivers; but unless ıs are employed to prevent it the same condition will again arise the limit of irrigation is reached under the storage systems osed.

hatever claims are made to the contrary, it is a fact that the area ıd to be irrigated in this portion of the Territory is much larger can be served by any possible water supply that can be made able for such irrigation. Neither Arizona nor Salt River Valley y exception in this regard to the rest of the arid region, but in ona and New Mexico the land and water are both still under the diction of the United States Government, and steps should at be taken to determine where and to what extent the water ırces can be most economically developed, and no irrigable land ld pass out of the hands of the Government for irrigation pur- s except such areas as it may be possible to irrigate. Persons ld not be allowed to obtain possession of the lands to be irrigated pt upon terms involving actual irrigation and cultivation. The

absurdity and wastefulness of the contrary policy are strikingly illustrated by a study of the map of the irrigated areas under the Florence Canal. More than a hundred thousand acres of irrigable land might be conveniently served by this canal if it had a sufficient quantity of water. There are, in fact, about 6,500 acres watered from it, very little of which lies near the canal, and most of which is in small isolated tracts. To water such tracts in such a manner requires not only a large amount of construction upon laterals, which under any rational system would be unnecessary, but it also involves an enormous loss of water through evaporation and seepage from the long laterals required to conduct the water to the small scattered patches of cultivated ground. The water flowing through the Florence Canal during the year 1896 was more than treble that which would be required to mature the crops grown in that year had it been economically distributed and applied.

The following summary of the various conditions and possibilities regarding the irrigated areas of the Gila River and Salt River valleys must be taken with a large allowance for error both regarding existing conditions and future possibilities. It is, however, of some value and interest as representing in round numbers the results of the best data at present available to the public.

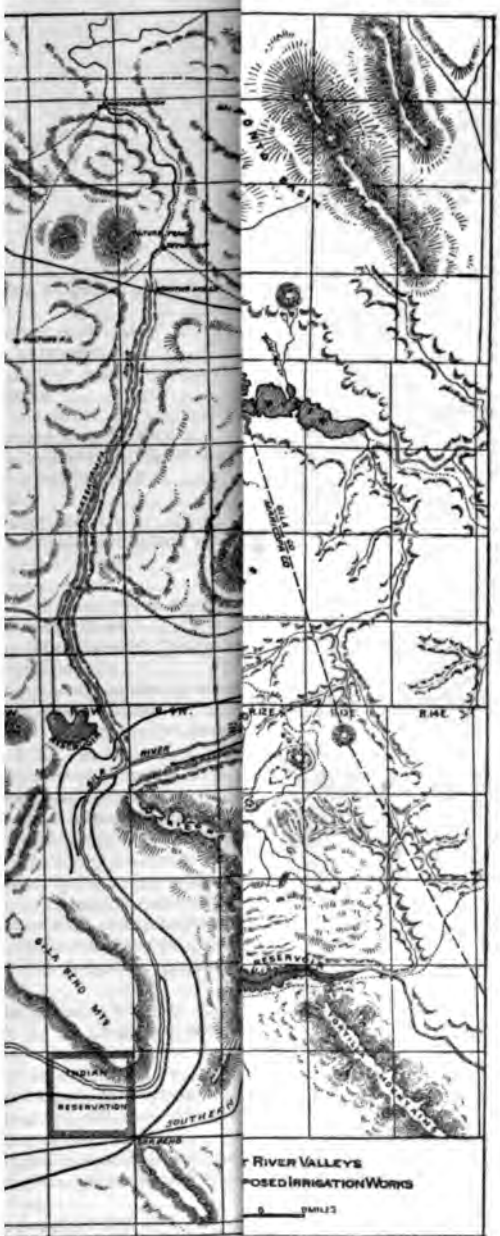
Summary of irrigation in Gila River and Salt River valleys.

	Acres.
Irrigated area in Cochise County	3,000
Irrigated area in Gila County	1,000
Irrigated area in Graham County	10,000
Irrigated area in Maricopa County	80,000
Irrigated area in Pima County	4,000
Irrigated area in Pinal County	7,000
Irrigated area in Yuma County	1,000
Total irrigated area	106,000

Additions may be made to the above area as follows:

	Acres.
Rio Verde Canal project, including New River Reservoir	150,000
Tonto Basin project	300,000
Agua Fria project, both reservoirs	80,000
Cave Creek project	10,000
Queen Creek project	5,000
Walnut Grove project	5,000
The Buttes Reservoir	100,000
Oatman Flat Reservoir	50,000
Various small reservoirs on tributaries of the Gila	50,000
Underground developments	20,000
Total	770,000
Already irrigated	106,000
Grand total	876,000

It is believed that these estimates are generous and that it will be very many years before the above figures are approached in actual practice. Of course other possibilities exist in Arizona from the use of the waters of the Colorado and its tributaries other than the Gila system. This estimate includes only the Gila system, and though the above figures are only rough estimates, they are suggestive of the importance to the future of Arizona of some comprehensive system of irrigation administration based upon principles of broad economy, and especially of the necessity of an exhaustive investigation of the water resources and of the most efficient means of utilizing them.


RIVER
GILA BEND MTS
INDIAN
RESERVATION
SOUTHERN
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R.14E.
RIVER VALLEYS
POSED IRRIGATION WORKS
0 MILES

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1894.

Report on agriculture by irrigation in the western part of the United States at the eleventh census, 1890, by F. H. Newell, 1894, quarto, 293 pp.

Contains a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also discusses the water supply, the value of water, artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the present condition and best possibilities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892–93, in two parts. Part II, Accompanying papers, 1894, octavo, 537 pp.

Contains papers on public lands of the western United States, by W. J. Meigs; natural mineral waters of the United States, by A. C. Peale; results of stream measurements, by F. H. Newell. Illustrated by maps and diagrams.

1895.

Fifteenth Annual Report of the United States Geological Survey, 1893–94, Part II, Progress of an economic character, 1895, octavo, 699 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell. Illustrated by a large map showing the relative extent and location of the several public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnaissance of northwestern Wyoming, by George D. Eldridge, 1894, octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Big Horn Range and the Yellowstone Valley, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar year 1893–94, by F. H. Newell, 1895, octavo, 178 pp. Bulletin No. 121 of the United States Geological Survey; price, 10 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Colorado, western Kansas, and eastern Nebraska.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896, octavo, 801 pp.

Contains papers by G. K. Gilbert on the underground waters of the Arkansas Valley in eastern Colorado; by Frank Leverett on the water resources of Illinois; and by F. H. Newell on a preliminary report on the artesian areas of a portion of the Dakotas.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, octavo, 250 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 30 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896, octavo, 300 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

Survey bulletins can be obtained only by prepayment of cost as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to The Director, United States Geological Survey, Washington, D. C.

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1897.
2. Irrigation near Phoenix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnaissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Sequoya waters of northern Utah, by Samuel Portter.
8. Windmills for irrigation, by E. C. Murphy.
9. Irrigation near Greeley, Colorado, by David Boyd.
10. Irrigation in Amalia Valley, New Mexico, by P. C. Barker.

In addition to the above, there are in various stages of preparation about [illegible] other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the geological survey in relation to the [illegible] flowing of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 2,000 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. (Approved, June 11, 1896). Stat. L. Vol. 29, p. 453.)

Application for these papers should be made either to members of Congress or to

THE DIRECTOR,
United States Geological Survey,
Washington, D. C.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 3

SEWAGE IRRIGATION.—DATTEN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal rep
relating to water supply and irrigation prepared by the United States Geolo
Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890, octavo, 123 p

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geolo
Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey, a preli
report on the organization and prosecution of the survey of the arid lands for purposes of
gation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, 295

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Ge
ical Survey: 1889-90. Contains a description of the hydrography of the arid region and o
engineering operations carried on by the Irrigation Survey during 1890; also the statement
the Director of the Survey to the House Committee on Irrigation, and other papers, includ
bibliography of irrigation literature. Illustrated by 28 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891, octavo, 570 p

Printed as Part II of the Twelfth Annual Report of the United States Geological Sur
1890-91. Contains a report upon the location and survey of reservoir sites during the
year ending June 30, 1891, by A. H. Thompson; "Hydrography of the arid regions," by
Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 40 plates and 130 fig

Bulletins of the Eleventh Census of the United States upon irrigation, prepa
by F. H. Newell, quarto.

No. 85, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 69, Irri
tion in Utah; No. 107, Irrigation in Wyoming; No. 152, Irrigation in Monta
No. 187, Irrigation in Idaho; No. 168, Irrigation in Nevada; No. 178, Irrigat
in Oregon; No. 188, Artesian wells for irrigation; No. 198, Irrigation in W
ington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No
September 9, 1892, quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings
total area and average size of irrigated farms in the subhumid regions, the percentage of
lot of farms irrigated, character of crops, value of irrigated lands, the average cost of irriga
the investment and profits, together with a résumé of the water supply and a description of
gation by artesian wells. Illustrated by colored maps showing the location and relative ex
of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Part
Irrigation, 1893, octavo, 486 pp.

Consists of three papers. Water supply for irrigation, by F. H. Newell; American engineer
and engineering results of the Irrigation Survey, by Herbert M. Wilson; Construction of
available maps and selection and survey of reservoir sites, by A. H. Thompson. Illustrate
71 plates and 178 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1
octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geolog
Survey; price, 15 cents.

Contains a description of the examination of the geologic structure of and adjacent to
drainage basin of Yakima River and the great plains of the Columbia in the east of this
with special reference to the occurrence of artesian waters.

(Continued on third page of cover.)

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

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UNITED STATES GEOLOGICAL SURVEY

No. 3

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

SEWAGE IRRIGATION

BY

GEORGE W. RAFTER

WASHINGTON

GOVERNMENT PRINTING OFFICE

1897

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, February 4, 1897.

R: I have the honor to transmit herewith a paper entitled "Sew-
Irrigation," by George W. Rafter, and to recommend that it be
lished as the third number of the series of papers upon water
ly and irrigation. The manuscript of this paper as submitted
Ir. Rafter contains a considerable number of details, which have
to a certain extent generalized, and also gives a discussion of
ge purification in the United States, with descriptions of the
s erected at various localities, together with an appendix con-
ng a list of publications relating to sewage irrigation. The limit
0 pages has, however, necessitated the dividing of the manuscript
two parts. The first constitutes this paper, while the latter has
held for publication in a future number of this series. It refers
ly to the results attained in various portions of the United States,
gives a few examples from the neighboring Province of Canada.
changes that have been made in Mr. Rafter's paper have been in
direction of adapting it to popular use, in order that the neces-
s and benefits of sewage irrigation may be more generally appre-
d by the public.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

on. CHARLES D. WALCOTT,
Director United States Geological Survey.

IRRIGATING CORN BY SEWAGE ON FILTER AREAS AT PLAINFIELD, NEW JERSEY

SEWAGE IRRIGATION.

By George W. Rafter.

IMPORTANCE OF SEWAGE IRRIGATION.

Owing to the rapid growth of urban population during the past few decades, and the consequent increase of pollution of streams from which water supplies are obtained, the subject of sewage disposal has come to be one of prime importance. As regards the United States, however, it is only within the past few years that the subject of sewage purification and its relation to the purity of streams has attracted general attention. In view of the large number of people concerned and the benefits to be derived from the dissemination of information on this subject, there is probably no topic relating to water supply and irrigation which is of greater importance to the country as a whole.

The citizens of all our municipalities are interested as a mere matter of sanitation in the innocuous disposal of sewage. Independent of commercial considerations, the towns should welcome any suggestion looking toward ridding them of what is in most cases a dead weight on the hands of the municipal authorities. The farmers, especially market gardeners in the vicinity of towns, should be able to utilize sewage with advantage to themselves, thus rendering beneficial what is otherwise a source of danger to health. It is the object of this paper[1] to point out to American farmers and to municipal authorities

[1]There is nothing especially new or original with the author in the methods of sewage irrigation which are here presented. It is merely proposed to describe, so far as possible in non-technical language and for the benefit of American farmers, not only what is being done to-day abroad, but also what is being done here at home. The author wishes in this connection to acknowledge his obligation to a number of sanitary engineers who have kindly placed at his disposal information and illustrative material embodied in this paper. In addition to courtesies received from gentlemen connected with the management and operation of sewage farms abroad, as acknowledged in the paper in connection with the discussion of the several farms described, the author is under special obligation to James Forest, esq., now honorary secretary of the Institution of Civil Engineers, for information as to how and where to see the best examples of sewage farming in England. Among American engineers to whom acknowledgment is due may be mentioned Samuel M. Gray, M. Am. Soc. C. E., of Providence; Allen Hazen, Assoc. M. Am. Soc. C. E., of Boston; Frank H. Snow, Assoc. M. Am. Soc. C. E., city engineer of Brockton, Massachusetts; George H. Carpenter, C. E., city engineer, Pawtucket, Rhode Island; Carroll Phillips Bassett, M. Am. Soc. C. E., civil and sanitary engineer, Summit, New Jersey; Benezette Williams, civil and sanitary engineer, Chicago; George H. Frost, C. E., business manager Engineering-News; M. N. Baker, Ph. B., associate editor of Engineering News; Col. George E. Waring, M. Inst. C. E., street commissioner, New York; and Harrison P. Eddy, C. E., superintendent of sewers, Worcester, Massachusetts.

the fact that under certain conditions sewage may be utilized with profit and to indicate in general terms how this may be done.

In the arid and semiarid portions of the West sewage utilization is of especial importance, for there every drop of water, especially during the summer season, is needed for the production of crops. The relatively small flow of the streams, combined with the warm climate, renders sewage especially obnoxious if not properly cared for, so that considerations of health and comfort are added to those of increased land values due to complete utilization of the water supply. The introduction of sewage irrigation in the West is more easily accomplished than in the East because of the general employment of water in agriculture. The first use of sewage in this connection in the West was probably at Cheyenne, Wyoming, in 1883. It has also been used at Colorado Springs and Trinidad, Colorado, at Fresno, Pasadena, Redding, Los Angeles, Santa Rosa, and Stockton, California, at Salt Lake City, Utah, and at Helena, Montana.

The popular idea, not only with us here at home but very largely abroad, is and has been that anything and everything connected with sewerage and sewage disposal is of so vile a character that it must be kept entirely out of sight. Out of sight, out of mind, has been the universal principle thus far. The immense aggregation of population in cities, however, by forcing the subject upon the attention of urban communities, has served to modify somewhat this popular misapprehension. At the present time the few persons who have thought out the rational view of these subjects hold that the old notion was, like many old notions, essentially wrong. Sewage is a great fact of existence, and the proper way is not to ignore it but to meet the problem on its merits, the same as other difficulties are met and overcome. In this spirit, in England, at any rate, it has become quite common to build the necessary works connected with sewerage and sewage disposal as ornamental as possible, and in the United States this plan has been likewise followed in a few places.

Sewage purification was first attempted in England about forty years ago. At that time extravagant and, in the main, essentially erroneous views were entertained as to the possibilities of its utilization in agriculture. Especially was this true as regards the manufacture of artificial fertilizers from the sludge of various chemical processes. Large investments of capital were made and concessions granted by towns to private companies, practically all of which were for processes of chemical purification. With very few exceptions these investments have all proved a dead loss. The purification of sewage by chemical treatment at a commercial profit has been found impracticable. In the meantime land processes, which have developed contemporaneously with the chemical purification processes, have in every sense held their own, until at the present time it can be

l that under proper conditions a fair profit may be made by the tivator from the utilization of sewage in agriculture.

bout twelve years ago the author began to collect information in ard to the pollution of streams and the purification of sewage, with cial reference to the conditions existing in the United States. At t time, aside from the work done by the Massachusetts State Board Health and that just begun by the city of Philadelphia, very little rmation was available as to stream pollution in this country; nec- arily one studying the subject must go to the foreign sources of rmation, and for this purpose nothing better could be found than voluminous English sanitary reports, issued from time to time various royal commissions and by a number of the large munici- ities of that country. But since about 1886 the subject of sewage ification and its relation to the purity of streams has received ch consideration in the United States, so that at the present time have over sixty purification works in operation. American data therefore accumulating rapidly, and we may hope in a few years re to have arrived at a full understanding of the more important nciples involved in sewage purification and the prevention of pol- ion of streams as applied to our special conditions.

The conditions here are quite different from those existing abroad. the first place, the streams are much larger, and so far as the pro- ction of mere effluvium nuisances is concerned they can take larger antities of sewage without offense, although it ought not to be over- ked that since many of our streams are the sources of public water pplies the effect of sewage pollution may be even more harmful than ough effluvium nuisances were produced, which, however unpleas- t to the sense of smell, are not always the source of special impair- nt of health. Again, it may be pointed out that land, even in the mediate vicinity of large towns, is much cheaper here than abroad. a number of cases in England the lands utilized for sewage irriga- n have cost as much as £400 to £500 per acre, whereas with us fre- ently suitable lands can be purchased within practicable distance towns for from one-quarter to one-eighth of these figures.

The large amount of experience gained abroad should have weight d value. For this reason an attempt is herein made to present sali- tly the current European practice of sewage utilization. We have ed too often to work out for ourselves what is popularly known as American method, ignoring the experience of others. We may as attain unto knowledge in the course of time, but meanwhile ny unprofitable investments will be made and money and time will unnecessarily lost. In this respect the conditions are similar to se seen in the development of ordinary forms of irrigation in the st, where frequently expensive works have been built and operated hout a knowledge of the water supply or other conditions. A very

cursory study of Old World irrigation would have saved considerable loss and resulted in more satisfactory results than those now attained. In many of these older countries, having physical and climatic conditions almost identical with our own, methods of agriculture and of controlling and utilizing water have been developed through the trials and failures of unnumbered generations. We are merely repeating many of their mistakes, and are only gradually coming to appreciate the fact that a more complete knowledge of the experience of the rest of mankind would be of incalculable value to us.

GENERAL PRINCIPLES.

The more important of the general principles discussed in this paper are brought together at this point for convenience of reference:

(1) Sewage purification is an imperative duty which municipalities owe to the owners of riparian rights, and which can not be neglected by municipalities without such an infringement upon those rights as it is now well established may be prevented by legal process.

(2) Sewage utilization should go hand in hand with purification. When operated with reference to all the necessary conditions, a proper degree of purification may be attained as well as satisfactory utilization.

(3) The proper method of utilizing sewage is, for purposes of irrigation, by means which do not differ, except in matters of detail, from those of ordinary irrigation as practiced abroad for centuries.

(4) In order to utilize sewage to the best advantage, the towns should construct, at their own expense, intermittent filtration areas on which the sewage may be efficiently purified when not required for use in agriculture. Farmers utilizing sewage in agriculture should be required to take it only as needed for the best results on crops.

(5) The theory of the action of intermittent filtration is in effect the theory of purification as effected by broad irrigation, the difference between the two being chiefly a matter of detail.

(6) In the purification of a strong acid sewage from manufacturing towns it may sometimes become desirable to treat the sewage by a chemical process before utilizing it in agriculture. For this purpose lime is the chemical commonly used.

(7) In case the effluent from sewage purification works or areas is to be passed into streams which are the source of drinking water for towns farther down, the degree of purification should necessarily be high. The experiments of the Massachusetts State Board of Health show that there is no trouble in removing from 95 to 99½ per cent of the organic impurity, as indicated either by the chemical constituents or by the bacteria. When as much as 99 per cent is removed, the sewage becomes chemically purer than the water of many wells, and there is, so far as known, absolutely no reason why it may not pass safely into a stream used as the source of a public water supply.

(8) Intermittent filtration areas are best constructed of coarse mor- r sand, as shown by the experiments of the Massachusetts State oard of Health.

(9) Intermittent filtration is chiefly a biological process, in which e nitrifying organisms, with the assistance of oxygen and the inerals naturally in solution in sewage, resolve objectionable organic atter into mineral nitrates, etc., the whole process, when properly nducted, taking place without the production of objectionable odor. he conditions for successful treatment are, generally, intermittency application and open spaces in the filtering material to which com- on air may easily gain access. Such filters may be expected to rify from 30,000 to 100,000 gallons per acre per day, the amount pending upon the quality of the material in respect to sand and ter content, as defined by the studies of Mr. Allen Hazen.[1]

(10) Sewage may be purified by broad irrigation at all seasons of e year at any place where the mean air temperature of the coldest onth is not lower than about 20° to 25° F., while by the use of inter- ittent filtration it may be purified fairly well down to a limit of ° to 20° F., provided the sewage reaches the purification area at a mperature not lower than about 45° F.

(11) From the experience gained abroad it is clear that we may ccessfully cultivate almost any of the ordinary agricultural produc- ons of the United States on sewage farms, due regard being had in ery case to the special conditions required for each particular crop.

(12) The most efficient purification of sewage can be attained by s application to land.

(13) On properly managed sewage farms the utilization of sewage not prejudicial to health.

(14) In comparing the results of sewage utilization as thus far btained in the United States with the results obtained abroad it is lear that, generally speaking, we have not been specially successful. s one chief step toward a remedy for this we need to create in this untry a class of sewage-farm managers who are thoroughly familiar ith all phases of the question. Thus far the management of Amer- an sewage farms has been usually in the hands of committees of unicipal councils having little or no knowledge of the real govern- g conditions.

(15) The experience in England, Germany, and France, and also at gained in this country, all points to intermittent filtration relief eas, on which any surplus sewage not required in agriculture may purified, as the rational method of procedure.

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[1] From 30,000 to 100,000 gallons of ordinary raw town sewage may be so thoroughly purified t it may be admitted to streams from which public water supplies are taken. If a less thor- h purification is required, or if the sewage has been previously treated with lime, from 000 to 300,000 gallons per acre per day may be successfully purified.

SEWAGE DEFINED.

Before proceeding to the main discussion, it is necessary to know the meaning of the terms in common use. By *sewerage* we refer to the general practice of removing the liquid and solid wastes of the human economy, as well as the washings of streets and manufacturing wastes, by water carriage. A *sewer* is the conduit in which, by the medium of water, such removal is effected. *Sewage* is the generic term, not only for the combined water and waste matter flowing in sewers, but also for the mixed solid and liquid matter handled either by pail or by pneumatic systems.

Ordinary city sewage contains a great variety of ingredients in addition to the waste water from kitchens, baths, laundries, and other domestic offices. In manufacturing districts it may contain the refuse substances of various manufacturing processes, the whole diluted with a considerable amount of water, to which, in rainy weather, in towns with combined sewerage systems, is added a large amount of sand and earth and organic matter from the street washings. With separate systems of sewers street washings are excluded, and the sewage, by reason of containing the house drainage only, has a much more uniform composition than is found in the sewage from combined systems; whence it results that the sewage from separate systems is somewhat more amenable to treatment, for two reasons: (1) because of more uniform composition; (2) on account of less variation in quantity. In case sewage is to be purified at sewage-disposal works, both these considerations lead to decrease in first cost of the works as well as to decrease in annual expense of operation. In case of utilization of sewage for irrigation, the same considerations lead to certainty and ease in the utilization as well as to decrease in the expense.[1]

In American cities, which use at least 60 to 100 gallons[2] of water per capita per day,[3] sewage is considerably more dilute than in foreign cities, where from 30 to 50 gallons per capita is more nearly the daily allowance. As remarked by Mr. Mills in the special report of the Massachusetts State Board of Health, we may say that the sewage of the average American town will contain something like 998 parts of water, 1 part of mineral matter, and 1 part of organic matter. The mineral matter, as it ordinarily exists in sewage, can not be considered as specially harmful, and from a sanitary point of view the object of

[1] See Sewage Disposal in the United States, Rafter and Baker, Chapter VIII, "General data of sewage disposal," and Chapter IV, "The self-purification of running streams," etc., for detailed discussion of fundamental points only briefly touched upon here.

[2] In all cases by gallons is understood the United States gallon of 231 cubic inches, or 0.1337 cubic feet.

[3] For information as to the use of water in American cities and towns in detail, see the Manual of American Water Works. A few cases are cited on page 16, following.

wage purification is chiefly to get rid of the one one-thousandth part organic matter.[1]

Comparing several series of analyses, both American and English, becomes apparent that ordinary town sewage in England is usually nsiderably more concentrated than that of the American towns. is very important to bear this in mind in applying English data to merican conditions. The elaborate experiments conducted by the assachusetts State Board of Health at Lawrence, and which have en reported from year to year in the annual reports of that board om 1888 to the present time, indicate that there is a relation between e purifying capacity of different filtrating materials and the amount impurity which can be removed from sewage of a given strength. his point is strongly brought out by the experiments conducted by e Massachusetts board. It follows, then, that if we prepare special eas of sewage purification in accordance with the indications of the assachusetts experiments we may expect to apply somewhat larger olumes of average American dilute town sewage per unit of area an has usually been found expedient in English practice. If, there-re, we use English data without reference to the quality of the soil which the sewage is to be applied, or of the sewage itself, we shall e likely to arrive, at times, at more or less erroneous conclusions.

As a summation of this part of the discussion, we may say that the ief object of sewage purification is to rid the sewage of the one one-ousandth part of organic matter which it contains, and that all of e appliances for sewage purification and utilization may be consid-ed as directed toward this one point.

QUANTITY OF SEWAGE.

In considering processes for the utilization of sewage, either in griculture or for its direct purification by chemical methods or by ntermittent filtration, it becomes necessary to learn, first of all, what uantity of sewage may be expected from a given population, and, asmuch as the flow of sewage will vary with the quantity of water upply, our first inquiry may be properly directed toward ascertain-ng the amount of water used in American towns. It may be pointed ut, however, and, indeed, strongly insisted upon, that general dis-ussion of this phase of the question can only be of use as indicating sted and approved methods of procedure. The conditions vary so reatly in different towns that each case must be taken by itself as a roblem for special solution.

If we examine statistics of the average consumption of water per nhabitant in the various cities of the United States, as given in the anual of American Water Works and in other publications, we

[1] See table in the Twenty-Sixth Annual Report of the State Board of Health of Massachusetts, 94, page 457, for the average composition of the sewage used in the experiments conducted t Lawrence by that board from 1888 to 1894, inclusive.

learn that there are wide variations. Without attempting to sh their extent here, we may cite the statistics of a few cities of t United States by way of illustration:

Average use of water in various cities of the United States.

City.	Population, 1890.	Daily use per inhabitant.
		Gallons.
New York	1,515,301	79
Chicago	1,099,850	140
Philadelphia	1,046,964	132
San Francisco	298,997	61
Buffalo	255,664	186
Washington	230,392	158
Allegheny, Pennsylvania	105,287	59
Lowell, Massachusetts	77,696	66
Fall River, Massachusetts	74,398	29
Cambridge, Massachusetts	70,028	64
Atlanta, Georgia	65,533	36
Dayton, Ohio	61,220	47
Troy, New York	60,956	125
Trenton, New Jersey	57,458	62
Portland, Oregon	46,385	203
Lawrence, Massachusetts	44,654	62
Manchester, New Hampshire	44,126	44
Williamsport, Pennsylvania	27,132	143
Birmingham, Alabama	26,178	162
Newton, Massachusetts	24,379	40

Many other cases could be cited from a vast mass of statistics be ing upon this subject now in existence, but the foregoing are suffici to show that the use of water in towns, both large and small, does follow any special law, and that the only way to proceed will be consider each case on its merits. On this point we may say t usually the use is smaller in towns provided with meter systems th in those without, and, further, that in those towns where meters being gradually introduced the tendency seems to be, on the wh toward a reduction per capita of consumption; all of which ag emphasizes the importance of studying each case on its merits.

In making arrangements for utilizing sewage in agriculture, or e for the purpose of purifying it in order to comply with sanitary requ ments, it is very important to take into account the future growth the town. The tendency of the last few decades has clearly beer the direction of great increase in urban population, as illustrated the reports of the last census.

In addition to variations in quantity of sewage due to varying uses of water in public supplies, we may frequently expect to find variations due to infiltration of drainage water into the sewers themselves, which will of course increase the flow of sewage over and above that due to the water supply, and to leakage from the sewers through gravel and other porous material and through the seams of rocks, which tends to decrease the flow below the amount due to the water supply. Both of these sources of variation will frequently operate to modify conclusions based upon water supply purely.

According to Frederick P. Stearns, M. Am. Soc. C. E.,[1] the amount of ground water finding its way into the sewers of the main drainage system of the city of Boston is about 45 gallons per capita per day. This large filtration is due chiefly to the fact that many of the older sewers of Boston are built of either dry or relatively open rubble masonry, while some of them follow the threads of old water courses, both of these circumstances leading to relatively large contributions of ground water.

At East Orange, New Jersey, a separate system of sewers was carried out in 1886 and 1888. The infiltration as measured before any house connections were in use was, for 25 miles of vitrified tile sewers, about 2.5 gallons per second. For the main brick sewer, 4,000 feet in length, the infiltration was 5 gallons per second. The total infiltration from the whole system amounted at these rates to 650,000 gallons per day. The flush-tank flow was taken at 30,000 gallons per day, and after the house connections were made the house-sewage flow from the contributing population of about 15,000 was taken at 620,000 per day; hence the infiltration was 50 per cent of the total quantity.[2] The remedy for a leakage into the sewers of this character may be found in improved methods of laying the sewers themselves. In any case it may be pointed out that an addition to the sewage flow proper of 50 per cent in the way of ground water is an unnecessary addition to the expense of sewage purification, should any be required.

We will assume, as regards the present argument, that the sewers of a separate system may, with careful workmanship, be made practically impervious, and that the sewage flow will therefore be about represented by the amount of the public water supply. We will further assume that there is no good reason why, in a properly managed municipality, there should be used more than from 60 to 80 gallons of water per capita per day. At this rate the sewage flow of a population of 10,000 would amount to from 600,000 to 800,000 gallons per day. In combined systems where the sewers receive the rainfall as well as the sewage proper it will be necessary to provide, in any purification project, for taking care of and properly purifying a considerable portion of the storm water at each rainfall.

[1] Special Report upon the Sewerage of the Mystic and Charles River Valleys, as made to the State Board of Health of Massachusetts.

[2] See Inland sewage disposal, with special reference to the East Orange (New Jersey) works, by Carroll Phillips Bassett, M. Am. Soc. C. E.: Trans. Am. Soc. Civil Eng., Vol. XXV, p. 125.

STREAM POLLUTION.

It is a well-established principle of law that every riparian proprietor is entitled to have a stream of water flow by his realty as it is wont to flow by nature. From this principle we have derived the old and well-settled doctrine that to pollute a public stream is to maintain a common nuisance. The necessities and conditions of modern society have, however, tended to some modification of this principle as thus strictly announced, so that at the present time there are certain reasonable pollutions of streams, or, rather, there are certain specific cases in which a stream may be polluted to some extent without abrogating the essential force of the fundamental proposition. At the same time it must be remembered that the broad proposition that streams ought not to be polluted is on the whole sound.[1] Admitting such premise, we are forced to the conclusion that some form of sewage purification is necessary wherever an aggregation of human beings in thickly settled communities leads to the production of any considerable amount of sewage.

If, however, towns or manufacturing establishments are situated on tide water, there is no reason why the sewage may not be disposed of by discharging it into the ocean, provided such a discharge can be made without creating a nuisance along inhabited beaches, and also provided it is clear that such discharge is, on the whole, financially to the advantage of the community furnishing the sewage. But if on examining all the attendant circumstances it appears that the sewage can be profitably utilized in agriculture, then there is no reason why such utilization may not be made, even in the case of towns situated on tide water. We need, therefore, as a necessary part of our subject, to discuss the general question of purification of streams. This question has been the subject of a large amount of discussion in England, where interest in it may be considered as dating from the first report of the Health of Towns Commission, made in 1844.[2]

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[1] The legal aspects of stream pollution as the matter stands to-day are discussed in Sewage Disposal in the United States, Chapter VI. The attention of the reader is specially directed to the views of the Massachusetts Drainage Commission as there given. The report of that commission may also be referred to, though, as it has long been out of print, it is now difficult to obtain.

[2] This commission made two reports: The first, in 1844, published in two octavo volumes; the second, in 1845, also in two octavo volumes. These two reports may be taken as the beginning of sanitary science in England and in the civilized world generally. Previous to and at that time the condition of the English towns, especially in the manufacturing districts, as shown by the information contained in these two reports, was such that the present generation can only with difficulty realize it. These reports should be studied by any person wishing to compass the whole subject of sewage utilization, by way of showing the magnitude of the evil which has been combated and greatly mitigated since 1844.

Among the subjects which this commission was especially charged with investigating were the causes of disease among the inhabitants as well as the best means of promoting and securing the public health. The commission pointed out a large number of cases where stream pollution was undoubtedly the cause of insanitary conditions, and the notable sanitary reforms which have placed England as regards sanitary improvements easily in the front rank of nations have all been perfected since that date. During the same period the literature of sanitation has been enriched by a number of valuable reports in which every possible phase of stream pollution has been discussed.

Without referring here to all of the various commissions in detail, we may cite the Royal Sanitary Commission of 1869, and the Rivers Pollution Commission. The former recommended that any stream from which drinking water is taken should be effectually protected from sewage pollution. The principle laid down at that time has been gradually extended until we now formulate it by the statement that streams which are even likely to be a source of water supply ought not to receive sewage pollution, or, if they do, only under such regulations as will admit of immediate discontinuance of the pollution whenever the water is required for domestic purposes.

The Rivers Pollution Commission[1] in their report point out not only the evils of pollution by sewage proper, but also those produced by pollution from manufacturing refuse. As regards this second class of pollutions, from manufacturing refuse, the following classification can be made: Pollution by dye, print, and bleach works; chemical works; tanneries; paper making; woolen works; silk works.

The reports of the Royal Commission on Metropolitan Sewage Discharge and of the Royal Commission on Metropolitan Water Supply also contain much information relating to stream pollution.

In this country stream pollution has been generally discussed by the State boards of health of Massachusetts, Connecticut, Illinois, and some of the other States. In Massachusetts the State Board of Health made the following recommendations many years ago:[2]

(1) That no city or town shall be allowed to discharge sewage into any water course or pond without first purifying it according to the best process at present known, which is irrigation; provided, that this regulation does not apply to a discharge from sewers already built, unless water supplies be thereby polluted; and

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[1] Rivers Pollution Commission (first commission). This commission made three reports. The first report deals generally with the best methods of preventing the pollution of rivers, with special reference to the conditions prevailing at that time on the River Thames. The second report deals with the River Lea. The third report deals with the rivers Ayr and Calder. Five volumes in all, 4°, London, 1866-67.

Rivers Pollution Commission (second commission). Report of the commissioners appointed in 1868 to inquire into the best means of preventing the pollution of rivers. This commission made six reports in all. The first report (2 volumes) treats of the pollution of the basin of the rivers Mersey and Ribble and of the best means of preventing pollution therein. The second report is taken up with a description of the A B C process of treating sewage. The third report (2 volumes) discusses the pollution arising from the woolen manufacture and processes connected therewith. Whoever would understand this division of stream pollution in all its phases should study this report. The fourth report treats of the pollution of the rivers of Scotland, and gives special consideration, among other subjects, to the pollution arising from paper-mill wastes, etc. The fifth report (2 volumes) treats of the pollution arising from mining operations and metal manufactures. The sixth report treats of the general subject of domestic water supply of Great Britain. A large amount of information about water supplies from cultivated and uncultivated areas and the contamination of water from manured and unmanured, cropped and uncropped land, is given, the whole forming a vast body of sanitary information pertinent to present conditions. Ten volumes, 4°, London, 1870-71-72-74.

[2] Seventh Annual Report, 1876, p. 12. To illustrate the pollution to which a single stream is subject, reference should be made to the Eighth Annual Report of the Massachusetts State Board of Health. In this it is stated that on the Nashua River are 92 mills, employing 5,543 persons. This stream drains an area of 437 square miles, with an average population of 106.5 to the square mile.

The reports of the Philadelphia water department, from the eighty-third to the eighty-sixth, inclusive, may be referred to for information in regard to stream pollution.

provided also, that any intended discharge of sewage can be shown to be at such point that no nuisance will arise from it.

(2) That no sewage of any kind, whether purified or not, be allowed to enter any pond or stream used for domestic purposes.

(3) That each water design should be regarded by itself in the preparation of plans for sewerage and water supplies.

(4) That accurate topographical surveys always be made of all towns before introducing water supplies or sewers.

(5) That steps should be taken by special legislation, based upon investigations and recommendations of experts, to meet cases of serious annoyance arising from defective arrangements for the disposal of sewage.

* * * * * * *

In the Tenth Annual Report of the Connecticut State Board of Health (1888), Prof. S. W. Williston, of Yale University, has given an excellent account of the wastes from manufacturing processes, which may be referred to as perhaps the most useful recent contribution to the literature of river pollution. At any rate, it easily ranks first among recent American contributions to that literature. Professor Williston takes up in his report the waste due to various manufacturing processes, such as brass working, iron working, paper making, woolen, cotton, and silk mills, and so on, and gives under each head the chief sources of pollution.

As to brass works, it is stated that they are productive of little sanitary injury to a stream, although the discharge of their chief waste, sulphate of copper, is the most poisonous to fish of any of the manufacturing wastes. Brass works, therefore, usually cause the fish to leave any stream which receives a considerable quantity of refuse from the works. Aside from sulphate of copper, the other waste products of brass works are acids and oils. In many of the brass manufacturing establishments, especially those using the electro-metallurgical process, considerable quantities of cyanide of potash and ammonia are used. Goods requiring electroplating are first treated with an alkali to remove any greasy matters adhering to the metal, and are then subjected to a dilute acid bath in order to remove the oxides from the surface. They are then placed in a cyanide of potash solution, which acts as the carrier in the deposition of the metal upon the surface plated.

Cyanide of potash is a virulent poison, and Professor Williston states that a sufficient quantity is annually employed in the Naugatuck Valley, in Connecticut, to destroy all the inhabitants of the United States. Most of it, however, is neutralized by the other chemicals used, so that it is doubtful whether its contaminating influence is very great.

In the manufacture of iron the only waste of importance is that from the pickling baths used for giving a nonoxidized surface to either wire or flat sheets which are to be galvanized. Such iron is dipped in a solution of dilute sulphuric acid and then washed in water, after which it is again dipped in a vat containing a heated solution of lime, to neutralize any small amount of acid not removed by the washing in water.

IRRIGATION ON SIDEHILL AS PRACTICED AT WAYNE, PENNSYLVANIA.

The chief waste from this process is sulphate of iron, which at many works is allowed to pass directly into streams, although not all of it is thus allowed to go to waste, as a number of the large rolling mills of the country have appliances for saving the sulphate of iron; as, for instance, the Cleveland Rolling Mill, at Cleveland, Ohio; the Ferric Chemical and Color Works, at Worcester, Massachusetts; and the Washburn & Moen Wire Works, also at Worcester. A large proportion of the crude sulphate of iron of commerce consumed in the United States is produced at these several works.

The waste products from paper manufacturing are both organic and inorganic in character. In mills using jute, gunny sacking and old rope, and other similar substances as the raw material, the organic wastes of the wash water may become a very serious source of pollution if discharged into small streams or if a considerable number of mills all discharge their wastes into a stream of considerable size. Caustic soda and lime are used for cleansing rags in places where rags are the raw material of paper manufacture. These wastes are usually allowed to pass into the stream. In mills using sulphite and wood pulps the wastes from the wash waters generally contain a considerable amount of objectionable substances, the bleaching process also requiring a considerable amount of chloride of lime, which, in this country at any rate, usually passes into the streams without treatment. The bleaching wastes are especially injurious to fish.

In a woolen manufactory the most serious wastes are those derived from the washing of the wool; constituting, as it does, chiefly organic material, it may be considered one of the most objectionable organic wastes. The raw wool of the ordinary grades, as it comes to the manufactory, contains a third or more by weight of organic matter; this is ordinary washed wool. Unwashed fine wools may contain as much as 50 to 60 per cent of organic matter, which is removed chiefly by scouring in alkaline solutions of soda, although in some mills urine is used in this process, as it is believed to give a softer finish to the manufactured article than can be obtained by the use of ordinary alkalies.

The woolen mills also furnish a large amount of dye waste, such as extracts of logwood, fustic, camwood, madder, etc., which are used in different methods of dyeing with various mordants, such as copperas, crude cream of tartar, bichromate of potash, alum, blue vitriol, and muriate of tin. After treatment in the dyeing vat, the wool is washed in running water and, usually, the contents of the vat are turned into the nearest stream. It is waste material of this sort that causes the chief complaints as to discoloration of streams by dye wastes. A certain amount of oil is also used in woolen manufacture, and more or less waste therefrom passes into the stream.

In manufacturing cotton goods the wastes are both organic and mineral, the former being the more serious. In the manufacture of

ginghams the following chemicals are commonly used: Sulphuric acid, nitric acid, muriatic acid, chloride of lime, sal soda, soda ash, bichromate of potash, alum, copperas, blue vitriol, lime, pearlash, stannate of soda, sugar of lead, indigo, cutch, sumac, alkali, soda, and the various aniline colors and dyes. Of the mineral matters, the most important are lime, chloride of lime, and bichromate of potash; of the organic dyestuffs, logwood. The waste from these various substances is usually allowed to pass without treatment into the streams.

In silk manufactures the raw silk as received is covered with a gummy substance which it is necessary to remove in order that the silk may possess the proper degree of pliableness. This silk gum, which is called sericine, constitutes from 20 to 25 per cent of raw silk and is mostly soluble in water. It is removed either by maceration or by scouring in a weak solution of soda. The refuse from these processes is usually turned into streams. The further processes of silk manufacture, as related to stream pollution, are those of dyeing, which are only of secondary importance. It is stated that there is less waste of dyestuff from silk mills than from mills manufacturing other kinds of fabrics.

In considering the effect of stream pollution we should bear in mind that all streams have some self-purifying power. Nature has provided in soils a natural agent for the innocuous resolution of organic matter into its simple constituent elements. The agent of nitrification exists in soils in vast quantities, and we may draw the conclusion that every rain washes these purifying agents into streams, where their work of destroying organic matter is continually going on, although not with the same degree of rapidity as in soils. One indispensable condition of the efficient action of the nitrifying agent is the presence of an adequate supply of oxygen. All natural waters contain more or less oxygen in solution, but unfortunately the stock is not large enough to admit of rapid action of the nitrifying agent. Hence it follows that, while it is true that the process of nitrification goes on in natural waters as in soils, it is also equally true that it proceeds much less rapidly there than in soils, with the result that a natural water is more easily overburdened with work of this character than a natural soil. This fact leads to the conclusion that soil is really the natural element in which to resolve objectionable organic matter into its simple, elementary forms, rather than water. Natural waters should be called upon to perform this duty only when no other means are available, it being remembered always that it is easy to overburden the purifying power of water in this direction.

It is still true that a stream may exert considerable self-purifying power, provided it is given time enough. This view is enforced by considering that in addition to the presence in our natural waters of the agent of nitrification there are also present certain classes of minute life which feed upon extraneous organic matter and which

without doubt resolve a considerable portion of it through the operations of the life process. The Entomostraca, Rotifera, and Infusoria are the principal agents assisting in such reduction. Of these the Entomostraca are probably the most important. This branch of our subject leads to biological studies of great interest and importance, but which for lack of space can not be more than referred to in this place.[1]

VALUE OF SEWAGE.

From an agricultural point of view the nitrogen, phosphoric acid, and potash are the most useful ingredients of sewage, and accordingly it becomes of interest to establish the quantity of these three elements which may be found in ordinary sewage. Taking that of about average composition,[2] a net ton may be expected to contain nitrogen to the amount of from 0.15 to 0.25 pounds; phosphoric acid, from 0.045 to 0.065 pounds; and potash, from 0.025 to 0.040 pounds. With nitrogen at 17 cents per pound, phosphoric acid at 7 cents, and potash at 5 cents, the theoretical value of the fertilizing ingredients of such a sewage would be, per net ton, from about 3.5 cents to 4.5 or 5 cents. Taking into account, however, the various losses of the nitrogen, which is not only the most valuable but also the least stable element, as well as the expense of distribution, we may conclude that the manurial constituents of sewage have an actual value, when applied to good advantage in agricultural utilization, of from 1 to 2 cents or perhaps 3 cents per ton. We should note that this is the manurial value only.

Independent of the manure, the water of sewage has also a distinct value for irrigation. But by reason of the variation in local conditions, it is impossible to make any general statement of value which will apply to all cases, although in a general way we may say, taking into account the manurial constituents as well as the irrigation value of the water, that sewage, when applied to land at the best advantage, may be considered, with the present understanding of things, as worth from 2 to 4 cents per net ton. In some cases, by reason of its value for irrigation, it may be worth several times these figures.

We learn, then, that the irrigation value of sewage may be quite as important as the distinctively manurial value, and it is believed that the recognition of this factor has placed sewage utilization on a somewhat different plane from that formerly occupied. In order to illustrate this point let us consider the matter briefly from an historical point of view.

When sewage disposal as a necessary concomitant of the sewerage

[1] For an extended presentation of this phase of the subject see discussion, by the author, of Dr. Charles G. Currier's paper on Self-purification of flowing water and the influence of polluted water in the causation of disease: Trans. Am. Soc. Civil Eng., Vol. XXIV, p. 70.

[2] See extended tabulations from Wolff and Lehmann in the first report of the Rivers Pollution Commission, p. 27. Also see Storer's Agriculture, Vol. II, p. 70.

of cities first grew up in England very extravagant views were entertained as to the commercial benefits to be derived from sewage utilization. Many hundred patents were taken out, mostly, however, on chemical processes, and large investments of capital were made, which have generally proved failures. Following these failures there was a reaction, during the prevalence of which it was held that sewage could not be utilized at a profit. When we examine the whole matter practically we find that the failure, in a commercial way, largely pertained to the chemical processes, although it should not be overlooked that many of the early sewage farms, by reason of poor management, unnecessarily expensive first cost, and other causes, have never been financially successful. We shall also see, farther on, that the best method of managing such farms has only recently been understood, which may be given as another reason why many of the early farms have not been financially successful. The net result of all this has been that many experienced engineers, sanitarians, and agriculturists have held that it was impossible to utilize sewage at a profit.

There is, however, another phase of the question. The main object of sewage purification is to keep streams pure and to preserve the health of the citizens of our cities and of the surrounding country. It has therefore been held, and very properly, that the real object of sewage treatment is purification and not utilization, and that utilization, by introducing commercial considerations, will inevitably tend to lower the degree of purification. It has been held, in short, that sewage purification is a right which one community or individual owes to another, independent of any question of commercial profit. And while this proposition is undoubtedly true, it is believed that, with proper understanding of all the elements of the problem, a satisfactory utilization may be also attained without lowering the standard of purification.

On this point the author's views have undergone some modification since he examined in detail a number of European sewage farms in the fall of 1894. Previous to that time he was disposed to believe that sewage disposal should be placed entirely on the broad plane of purification rather than on that of utilization. At the present time he believes, as the result of seeing what is being done on the best sewage farms of England, Germany, and France, that the agricultural value of sewage may be fairly utilized, and still a high degree of purification attained.

Since the first development of sewage utilization in England the trade in commercial fertilizers has also greatly extended, and many writers have taken the ground that at the prevailing prices of commercial fertilizers agricultural lands can be manured more cheaply by their use than by the use of raw sewage.[1] In regions where the distribution of the rainfall is such as to fairly meet the necessities of

[1] *See Agriculture in some of its Relations with Chemistry*, by F. H. Storer, Vol. II, on this point.

e this is probably true, but it is believed, with the present
, that in any region where the distribution of the rainfall
ıat periods of drought are likely to occur at the critical
growing crops, provided sewage can be delivered upon agri-
ınds by gravity, or even by a moderate pumping lift, a com-
ıving will be effected, due to the irrigation value of the
ver any gain that can possibly be obtained by the use of
ıl fertilizers alone. If pumping is required, its cost may,
enter in as a modifying element. At any rate the author
place this thought before the scientific farmers of the
ates as one well worthy of their most careful consideration.
s further to say that from the experience gained in other
as well as our own, he believes that frequently lands in the
vicinity of our cities and towns can be improved in pro-
ss more by the general application of sewage irrigation than
ıer method at present open to our farmers.
ld be remembered, however, that the quality of soils will
the final solution of the problem. Those best suited for
rigation are open, porous, gravelly soils, while heavy clay
demand so great an expense of preparation as to render
ilization, except in special cases, practically impossible. As
nted, each location presents its own special problem, which,
xtent, will demand its own special solution independent of
cases. It can not be too strongly insisted, therefore, that
must be studied by itself on its own merits; hence the
statements are to be taken as general statements rather
ersally true propositions.

METHODS OF SEWAGE DISPOSAL.

esult of a large amount of experience gained abroad, sew-
sal or purification has resolved itself into three general
which are known as (1) chemical precipitation, (2) intermit-
tion, and (3) broad irrigation. In the present paper we are
ılly concerned with chemical treatment, except as at times
t of irrigation; nor are we concerned with intermittent fil-
:cept so far as it may be considered an adjunct of irrigation.
etion of the subject, however, we may briefly describe the
treatment known as chemical precipitation.[1]

CHEMICAL PRECIPITATION.

process the sewage is allowed to flow into large tanks, in
s dosed with certain chemicals; these form with the organic
ıts an insoluble precipitate, which in its descent to the bot-
tank may, under favorable circumstances, carry down with

plete descriptions may be found in the several standard treatises recently issued,
e, Crimp's Sewage Disposal, Wardle's Sewage Treatment and Disposal, and Rafter
ewage Disposal in the United States.

it the suspended matter of the sewage as well as a portion of the dissolved. To apply this treatment on a large scale, extensive works with a large number of tanks, together with machines for grinding and mixing the chemicals, as well as special mechanical arrangements for mixing the chemicals and sewage and caring for the sludge, are required, the whole including what is commonly called the chemical treatment of sewage, although the complete process is in reality partly chemical and partly mechanical.

The reagents now generally used are common lime, sulphate of alumina, and ferrous sulphite. These reagents are used either singly or in combination, as may be required to fit the case of each particular sewage undergoing treatment. The action of the reagents in producing a precipitation of the organic matter is not fully understood, although in a general way we may say that when lime is used there

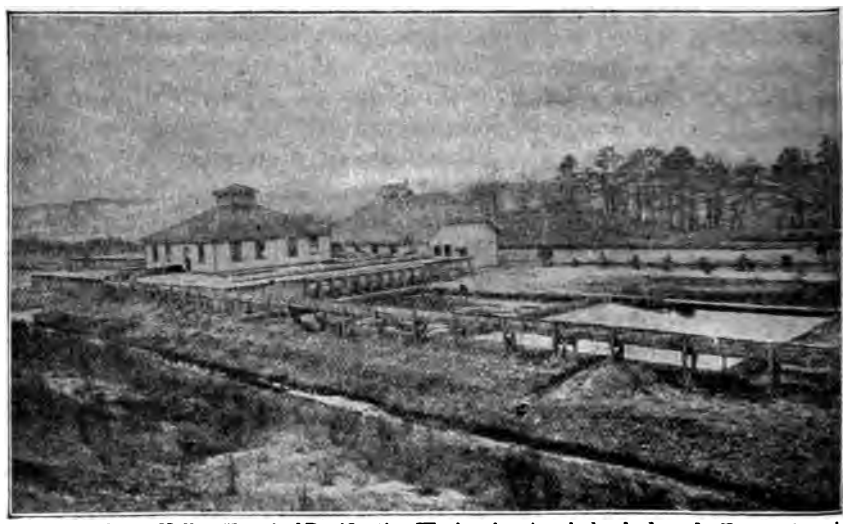


FIG. 1.—Mystic Valley Chemical Purification Works, showing sludge beds and effluent channel.

is a combination of some of the lime with free carbonic acid gas to form an insoluble carbonate of lime; also, probably, an additional part of the lime combines with a certain portion of the organic matters in solution to form an insoluble precipitate, which in its journey to the bottom carries down with it any portion of the suspended matters which have not entered into combination. The matter settling to the bottom is called sludge.

When sulphate of alumina is used, the precipitating effect is considered as due to a combination of the sulphuric acid of the sulphate of alumina with lime and other mineral bases existing naturally in the sewage. A flocculent alumina hydrate is also formed, which in conjunction with the mineral precipitate further entangles and carries down any suspended organic matter. At the present time, as a general statement, we may say that a combination treatment of lime and

sulphate of alumina is preferable for ordinary sewage to the use of either of them alone, although the composition of the sewage should be taken into account in deciding.

In the case of ferrous sulphate, in order to secure a precipitating action it is necessary either that the sewage be naturally alkaline or, if not naturally so, that an alkali be artificially added. The result of this treatment is the formation of a flocculent hydrated oxide which carries down with it the suspended organic matter as well as a portion of the dissolved.

In order to insure the best results in chemical treatment the sewage should be treated while fresh and the chemicals added to the flowing sewage, in order that they may become fairly incorporated before it passes into the settling tanks. There should also be enough tank space to insure a thorough precipitation. Inasmuch as the sludge must be frequently removed from the bottom of the tanks, the mechanical arrangements should be such as to permit of its removal without interruption of the works.

Methods of chemical treatment may be classified as (1) intermittent treatment in shallow tanks from 5 to 8 feet deep, in which, after the addition and incorporation of the chemicals, the sewage is allowed to remain undisturbed until the completion of the process, when the clarified liquid is drawn off the top, leaving the sludge at the bottom; (2) continuous treatment in a similar series of tanks through which, after the addition and incorporation of the reagents, the sewage is allowed to flow slowly, crude sewage with freshly added chemicals passing in at one end and purified effluent passing out at the other; (3) vertical tanks through which, after the addition of the chemicals, the sewage rises slowly. At the present time the continuous treatment, in which crude sewage with freshly added chemicals passes in at one end and purified effluent passes out at the other continuously, is considered, as the result of experience, to be the preferable method of applying the chemical treatment.

As to the tank capacity required, we may say that in systems which are arranged with reference to receiving a portion of the rainfall the daily capacity should be nearly 50 per cent of the average daily flow, an allowance of this kind giving some leeway for contingencies when required. With the sewage from separate systems of sewers less leeway will be required.

Various methods of disposing of sludge have been used. One is to pump it into basins, from which it is subsequently conveyed to adjacent areas for utilization as fertilizer. It is also frequently deposited in large open basins surrounded by embankments, from which, after the larger portion of the water has drained away, it is removed either for use as a fertilizer or to some other point for filling in low land, etc. The liquid sludge is also sometimes run directly onto agricultural areas, where it is easily disposed of by plowing in. It may also be mixed with *combustibles* and disposed of by burning. In some cases

it has been used to form compost heaps by mixing with earth, rubbish, vegetable mold, gypsum, stable manure, leaves, or other suitable materials. When disposal works are situated near tide water, the sludge may be disposed of by running it into dumping scows, which convey it to deep water for dumping. It may also be burned in a furnace similar to the garbage destructor, but for this purpose it requires partial desiccation before treatment. On the whole, the most practicable way of treatment is to compress it into solid cakes by the use of a filter press. In this form it is entirely innocuous, and may be stored, handled, or conveniently transported for use, either as a fertilizer or for filling in low lands or for other purposes. The liquid sludge, as it ordinarily comes from the settling tanks, contains from 90 to 95 per cent water and from 5 to 10 per cent solid matter.

The mixing of the chemicals with the sewage is effected either by the use of baffle boards in the conduit leading to the tanks, or, where this is impracticable, by the use of mixing wheels. As the problem is merely one of thorough mixing, it is unnecessary to discuss it at length. Usually very simple mechanical appliances are sufficient.

At the present time lime containing from 65 to 75 per cent available calcic oxide can be purchased in the eastern part of the United States at from $8 to $9 per net ton; ferrous sulphate or copperas containing 26 per cent of ferrous oxide can be bought at about $15 per net ton, and sulphate of alumina, containing 14 per cent of alumina, at about $25 per net ton. The exact price of these reagents of course varies in different localities as well as with the quality of the reagent itself.

In 1889 Mr. Allen Hazen, at that time chemist in charge at the Lawrence experiment station of the Massachusetts State Board of Health, carried out a very elaborate series of experiments on the chemical treatment of sewage. The details of these experiments may be found in the twenty-first annual report of that board, to which, inasmuch as we are not concerned other than generally with chemical treatment of sewage, the reader is referred for a more extended account. We may, however, refer to the following statement of costs per capita in comparison with degree of purification obtained, as given by Mr. Hazen.

Taking the percentage of albuminoid ammonia removed to represent organic matter, the experiments on chemical precipitation show that in addition to all suspended matter the following amounts of soluble organic matter may be removed:

	Per cent.
With lime, costing 30 cents per inhabitant annually	22
With copperas and lime, costing 30 cents annually	39
With aluminium sulphate, costing 30 cents annually	20
With aluminium sulphate, costing 40 cents annually	39
With lime, costing 27 cents annually	30
With copperas and lime, costing 20 cents annually	13
With copperas and lime, costing 31 cents annually	39
With aluminium sulphate, costing 23 cents annually	10
With aluminium sulphate costing 45 cents annually	47

By way of disposing in this place of the question of relative degree of purification attained by the different processes, it may be remarked that there is now a vast body of information—not only special experimentation like that at Lawrence, but results obtained in actual practice—all showing that land-treatment methods, when properly operated, easily remove all the suspended organic matter of sewage as well as from 95 to 99.5 per cent of the dissolved matter. As a problem of efficient purification, therefore, the superior efficacy of the land treatments may be conceded without further discussion.

INTERMITTENT FILTRATION.

In 1868 a commission, consisting of Sir William Thomas Denison, Edward Frankland, and John Chalmers Morton, was appointed to inquire how far the use of rivers or running waters in England for carrying off the sewage of towns and the refuse of manufacturing processes could be prevented without risk to the public health or injury to such processes in manufactures, and also how far such sewage and refuse could be utilized and got rid of otherwise than by discharge into rivers or running waters, or rendered harmless before reaching them. The commission was further charged with an inquiry into the effect on the drainage of lands and inhabited places of obstruction to the natural flow of rivers or streams as caused by mills, weirs, locks, and other hydraulic works, and into the best means of remedying any evils thence arising. The commission so appointed is commonly known as the Rivers Pollution Commission, although it was in reality the second of this name.[1] Dr. Edward Frankland, the chemist member of this commission, was at that time by far the ablest chemist in England, and the vast amount of original chemical investigation given in the commission's six reports is a monument to his genius for sanitary chemistry and to his capacity for work.

In the first report, issued in 1870, the commissioners discuss various experiments on filtration which had been carried out under the direction of Dr. Frankland. Among others, the statement is made that the practice of filtration of sewage through sand, gravel, clay, or certain kinds of soil, if properly carried out, is the most effective method for the purification of sewage to which reference had at that time been made. A series of experiments on soil of various character is also discussed in detail, from which it is concluded that the process of purification through soil is essentially one of oxidation, the organic matter being to a large extent converted into carbonic acid, water, and nitric acid.

As one of the necessary conditions of intermittent filtration, it is also shown that a continuous aeration of the filtering medium must be secured. In discussing this phase of the subject the commissioners point out that the inability to continually aerate the filtering

[1] See footnote on page 19.

medium is a chief reason why purification of sewage by upward filtration will necessarily be less effective than by the opposite or downward filtration; hence the name "intermittent downward filtration," as originally attached to this process. The theory is discussed in too much detail in the report in question to admit of more than casual mention here. As the result of the commission's work on this line, it was concluded that a new method of sewage purification had been brought out. On this point the commissioners remark in their summary that towns and manufacturers have the means of rendering the organic impurities dissolved in their waste waters so far harmless by slowly passing them through well-aerated filter beds as to admit of their being again useful for manufacturing purposes.

The experiments carried out in the commission's laboratory showed that a properly conducted system of intermittent filtration would cleanse town sewage sufficiently to enable it to be used for all but domestic purposes. The result of the treatment is a true oxidation, and consequently an entire transformation of nearly the whole of the organic matter in the sewage. From the remedial point of view the new treatment was therefore considered successful. But the commission remarks that, since sewage possesses high agricultural [illegible] this method of treatment, if universally adopted, would be very [illegible] ful, and is therefore only to be recommended on a small scale or [illegible] circumstances render any other process, such as sewage irrig[illegible] difficult or expensive. The commission, however, believed that [illegible] operation of sewage purification by intermittent filtration could [illegible] conducted without serious nuisance.

While the commission thus announces a new and valuable discovery in sewage purification, still it expresses in the final summary the opinion that in all practicable cases broad irrigation should be used in preference to intermittent filtration, because, when irrigation is carefully and properly conducted, not only is sewage rendered inoffensive, but some return of profit may be derived from its employment. In the commissioners' opinion all the experiments made to that date went to show that sewage can be most beneficially employed as a manure, and that it is thus also most perfectly cleansed.

The Rivers Pollution Commission, while originating intermittent downward filtration and strongly recommending its use under proper conditions, still, rather singularly, did not propose a complete definition of it as a process of sewage purification. In 1882 a commission[1] was issued to George William Wilshere, the Baron Bramwell, Sir John Coode, and others to inquire and report upon the system under which sewage is discharged into the River Thames by the Metropolitan Board of Works, and whether any evil effects resulted therefrom; and if so.

[1] Metropolitan Sewage Discharge, Report of Royal Commissioners, 4 volumes of reports, minutes of evidence, appendices, etc., 4°, London, 1884-85. Presents every phase of the question of *disposal* of sewage of London as it existed twelve years ago.

what measures could be applied for remedying the same. This commission is known as the Royal Commission on Metropolitan Sewage Discharge. In its second report we find a definition of the difference between broad irrigation and intermittent filtration, in the following terms: Broad irrigation means the distribution of sewage over a large surface of ordinary agricultural ground, having in view the maximum growth of vegetation (consistent with due purification) for the kind of sewage supplied. Filtration means the concentration of sewage at short intervals on an area of specially chosen porous ground as small as will absorb and cleanse it, not excluding vegetation, but making the produce of secondary importance. The intermittency of application is a sine qua non, even in suitably constituted soils, wherever complete success is aimed at.

As to the value of intermittent filtration, the Royal Commission on

FIG. 2.—Filter area, with absorption ditches, as laid out in England.

Metropolitan Sewage Discharge states that, in its opinion, the process has great scientific merit and affords valuable practical advantages for the disposal of sewage in situations where broad irrigation is impracticable and where land suitable for filtration can be obtained. If, however, there should be a difficulty in obtaining sufficient area of land, the commission is of the opinion that, before applying it to land, sewage should be previously treated by some efficient process for removing the sludge. The recent studies of intermittent filtration by the Massachusetts State Board of Health have greatly advanced our knowledge of the true theory of intermittent filtration, although, as we have seen, the broad lines were well established by the Rivers Pollution Commission in its first report, issued in 1870.

Taking into account the present views, we may define intermittent

filtration as a natural process of biologically reducing the nitrogen of complex, nitrogenous, organic matter to the simple forms of mineral nitrates and, probably, free nitrogen, the reducing action being due to two minute bacilli known as the nitrous and nitric organisms or ferments. The immediate result of the work of the nitrous organism is to convert ammonia into nitrite, while the nitric organism converts nitrite or nitrous acid into nitric acid, which, uniting with mineral bases, immediately forms mineral nitrates. The organisms producing these changes exist naturally in soils, and when specially prepared areas are properly treated develop in the interstices in vast quantities.

NITRIFYING FERMENTS.

No more fascinating chapter of science can be found than that pertaining to the development of our present knowledge of the real office of the nitrifying ferments. For many years the subject has been one of prolonged study by a number of the leading chemists and biologists of the age. Among these may be mentioned Schwann, Schultze, Pasteur, Schloesing, Muntz, Heraeus, P. F. Frankland, Warington, Winogradsky, and the biologists of the Massachusetts State Board of Health, working under the direction of Professor Sedgwick in that board's laboratory at Boston. Beginning with the

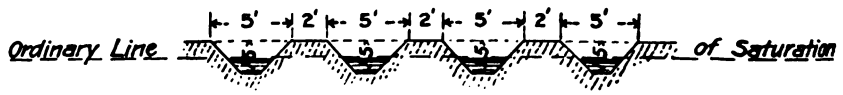


FIG. 3.—Section of absorption ditches.

work of Schwann and Schultze, as early as 1839, and ending with the work of Warington, Winogradsky, and the biologists of the Massachusetts board, we find a progressive advance from a knowledge, as the first step, that the decomposition of nitrogenous matter is due solely to the small vegetable organisms known as bacteria, to the final demonstration that the production of nitric acid is also due to a similar class of organisms. The complete account of the failures and successes encountered in the successive steps of the study is one of the romances of modern biology.

Without going into details, we will refer to two papers by Mr. Warington, one before the English Society of Arts, as published in that society's journal of April, 1882, the other as read before the British Association for the Advancement of Science at its annual meeting at Montreal in 1884. In his paper before the Society of Arts Mr. Warington set forth the theory of sewage purification by soil so clearly that we may draw upon it as perhaps, on the whole, the best concise general statement of the specific problem now under discussion thus far made. The paper begins by stating that dilute solutions of urine, which contain the essential constituents of plant food, undergo no nitrification when fully exposed to the air if only they have been previously

boiled and the air supplied to them is filtered through cotton wool. If we add a small particle of fresh soil to sterilized solutions of this character, no action at first appears, but after a while nitrification begins and the ammonia of the urine is converted into nitrate. This action proceeds best in the dark, and its full completion requires the presence of some mineral base, as, for instance, lime. A solution which has undergone nitrification is capable of producing nitrification in another sterilized solution which, without the addition of the nitrified solution, would remain unchanged. If we boil the soil or the nitrified solution, we destroy the power of causing nitrification. As a final point, Mr. Warington states that nitrification is confined to the same range of temperature which limits other kinds of fermentation. At or near the freezing point the production of nitrates proceeds very slowly, but increases in rapidity with a rise of temperature, reaching its maximum at 99° F. Above this temperature the rate of nitrification diminishes, nearly ceasing at 122° F., and entirely ceasing at 131° F.

Mr. Warington also states that the purifying action of soil on sewage is probably due to three distinct causes: (1) Simple filtration, or the separation of suspended matter; (2) the precipitation and reduction by the soil of ammonia and various organic substances previously in solution; (3) the oxidation of ammonia and organic matter by the agency of living organisms. It is considered that the last mode of action is the most important, as without it sewage matter would accumulate in the soil and the filter area soon loose its efficiency. The simple filtering power of the soil will depend upon its mechanical condition, while the precipitating power is a chemical function, in which the hydrated ferric oxide and alumina and the silicates of soils probably play the principal part. The oxidizing power will depend partly on its mechanical, partly on its chemical, and partly on its biological condition. We now know that a porous medium is not absolutely essential for nitrification and that sewage may be nitrified in a glass bottle or when passing over polished pebbles. Although porosity is by no means essential to the nitrifying power of soil, it is a condition having a very favorable influence on the rapidity of the process, porous soil of open texture presenting an immense surface, which will become covered with a thin film of the nitrifying organisms, and which, by reason of its porosity, will be well supplied with the air requisite for the discharge of other functions. This fact explains why nitrification takes place more rapidly in soil than in liquid.

In his paper before the British Association in 1884 Mr. Warington remarks that further proof of the ferment theory is afforded by the fact that antiseptics had been found fatal to nitrification. In the presence of a small quantity of chloroform, carbon bisulphide, salicylic acid, and, apparently, also phenol nitrification entirely ceases. The action of heat is also equally confirmatory. Mr. Warington also refers to experiments as carried out at the Rothamsted experimental

station, in which small quantities of the soil were taken at depths varying from 2 inches to 8 feet from freshly cut surface on the side of pits sunk in clay soil. The soil so removed was at once transferred to a sterilized solution of dilute urine, which was afterwards examined from time to time to ascertain the degree of nitrification. From the results it appeared that in a clay soil the nitrifying organism is confined to about 18 inches of the top soil, and is most abundant in the first 6 inches. In a sandy soil, he remarks, we would expect to find the organism at a lower level than in clay, but at that time there was no direct evidence, although since then the later investigations have shown the presence of the nitrifying organisms at as great a depth in porous soils as 4 feet.

Another paper or series of papers by Mr. Warington which may be referred to is his six lectures on the investigations at the Rothamsted Agricultural Station before the Association of American Agricultural Colleges and Experiment Stations, at Washington, in August, 1891. In these lectures Mr. Warington brings the whole subject of nitrification down to date, but with such wealth of detail as to preclude more than a simple reference to the matter here. The reader interested in this particular phase of the subject can hardly do better than to study the lectures in question.

We have seen that Mr. Warington pointed out in his paper of 1882 that antiseptics are fatal to the life of the nitrifying organism. In the course of the experiments at Lawrence, Massachusetts, a number were made as to the effect upon nitrification of antiseptics, as well as other substances, among these being ammonium chloride, alkalies, acids, common salt, and sugar. The results indicated that many substances which would ordinarily be fatal to the nitrifying power of a filter if applied suddenly, can be efficiently treated provided the increase in quantity is gradual, thus giving the filter time in which to adapt itself to the various grades of work.

ESSENTIAL CONDITIONS.

We have seen that Mr. Warington pointed out in his paper of 1882 why porous soils would be much more favorable for intermittent filtration than those of close texture. We may now examine as to the quality of some best suited for such work.

In the Twentieth Annual Report of the Massachusetts State Board of Health we find stated as a fundamental proposition of intermittent filtration that sewage can be more efficiently filtered through open sand than through sand covered with soil, and that the upper layers of intermittent filtration areas should be of coarse sand, into which the sewage will disappear rapidly, leaving room for air to enter and come in contact with the thin laminæ of liquid covering the particles of sand. As regards the purification of sewage through the medium of nitrification, the chief points established are that the best results are

obtained in filters which have been for some time in work, thus becoming adapted to the special service they are to perform; that free oxygen is indispensable for success; that sewage is best purified when held in thin films upon or between sand grains and gravel stones; and that the period of greatest distribution of the ordinary sewage bacteria corresponds with the time of most active nitrification. The experiments also indicate that the nitrifying organism probably attaches itself in very thin films over the surface of the sand grains and gravel stones of the filter area, and that for complete nitrification the sewage should remain in contact with the nitrifying organism a short space of time. If while in such contact the conditions are favorable to the complete admission of oxygen, we may expect the purification to be very complete. So important is this consideration that Mr. Allen Hazen, in one of his reports, has formulated the indispensable conditions of sewage purification as depending upon oxygen and time. All other conditions, Mr. Hazen says, are secondary. Even temperature is only a minor influence. If the organisms for purification have attached themselves to the sand grains and imperfect purification then occurs for any considerable period, it is conclusive evidence, Mr. Hazen says, either that there is too small a quantity of oxygen present in the filter or that the sewage is passing through so rapidly as not to afford time for complete oxidation. In a practical way, therefore, such filters must be so operated as to insure a slow enough rate to give the necessary contact between the sewage and the nitrifying organisms, while at the same time insuring the presence of an abundance of free oxygen in the interstices of the filter. Moreover, we must not overlook the necessity for the presence of an alkaline basic salt, and the fact that the temperature of the filter area generally must be somewhat above freezing, although it is true that such filters will operate below freezing for considerable periods of time without entire cessation of the nitrifying process. As to the alkaline base, if it does not exist naturally in the filtering material used it may be added artificially. For this purpose common lime sown broadcast over the area answers every requirement.

The experiments at Lawrence have been carried out with reference to materials of varying degrees of coarseness. In some of the tanks coarse mortar sands have been used, while in others sands of medium quality, as well as fine sands, have been experimented upon. One of the most interesting special experiments is as to the filtering qualities of a very fine sand in situ.

For the purpose of this experiment a natural area of fine river silt of about one-third of an acre was prepared by partial underdraining with drains 60 feet apart, which were designed chiefly to catch samples of the effluent. This area is on the banks of the Merrimac River, near the experiment station at Lawrence, Massachusetts, with its surface several feet above the ordinary stage of the river. The few

underdrains laid were found of little use, because usually the liquid passes by them directly down to the plane of the water table. The surface of the location selected slopes at the rate of about 1 foot in 10 in one direction and about 1 in 100 in the other. A series of shallow trenches which follow the surface of the field are excavated in the original material. They are mostly made 1 foot wide top and bottom, with varying depths from 6 inches to 3 feet, and filled in with a coarse mortar sand. They are 5 feet apart, and are generally constructed with the surface of the coarse sand 4 inches below the adjacent original surface, except at the lower end, where, in a distance of 50 feet, the depth increases to 10 inches below the original surface. These trenches are each about 200 feet in length. The distance which sewage will flow in them varies with the amount applied and the amount of sediment upon the surface, which again varies with the quality of the sewage, the completeness of the nitrification, and the time elapsed since the surface was cleaned. As to the cleaning of the surface, it is found desirable that it be done occasionally, usually at periods of from one to three months. The removal of a quarter of an inch in depth from the surface of the coarse sand appears to be sufficient. During the winter the trenches have been covered with boards, with the result that the process of purification proceeded readily during the entire winter.

The result of this experiment indicates that in very fine sand of the quality here found from 50,000 to 60,000 gallons of sewage per day may be efficiently purified with a renewal of the sand in the trenches of perhaps 2 to 3 inches annually. Filters composed of either coarse mortar, sand or fine gravel, or coarse sand and gravel mixed may be expected, however, to filter from 80,000 to 100,000 gallons per day per acre.

Experiments with fine soil, with sand covered with soil, and with peat and loam and coarse gravel have all been carried out in great detail at Lawrence. The wealth of material relating to these different experiments precludes any adequate reference to all of them in this place. A few of the more interesting may be briefly referred to. For instance, one of the most important results brought out by the miscellaneous experiments is the fact that by systematically breaking the scum which forms on the surface of the filters a very much larger quantity of sewage can be purified without deterioration of the effluent than is possible when the scum is allowed to remain unbroken for long periods of time.

PERMANENCY OF SAND FILTERS.

As to the permanency of such filters, it is remarked that the leading fact of intermittent filtration is that the organic matters of sewage are destroyed instead of being stored in the filter, as is largely the case with other methods of purification. The experiments have further shown that the conditions allowing thorough purification of the

maximum volume with the best results are such that a small percentage of the more stable organic matters of the sewage resist the reducing action of the filter and tend to accumulate in its upper layers, until after a time the surface becomes choked to such an extent that the sewage will not sink freely below it, thus violating the fundamental principle of intermittent filtration. As a remedy it is suggested that temporary relief may be obtained by simply turning the surface under, although evidently an indefinite use of the same material would be impracticable if anything like a maximum quantity of sewage were treated. Since the organic material thus accumulating is confined entirely to the upper few inches of the filter, it is considered best to occasionally renew the upper layers of sand.

Experiments were also made as to the nature of the clogging material, with the result of showing that it may be divided into two classes, the fats and the sludges proper, the former being in effect the carbonaceous element and the latter the nitrogenous. The result of the experiments is to indicate that the fats themselves do not accumulate in the sand in such a way as to choke the filter. The possibility is pointed out, however, that instead of being completely oxidized and destroyed the fats may be oxidized to some stable compound which clogs the sand. The experiments apparently indicate some action of that sort which thus far has not been well defined. It has been found that clogging is in no way a serious matter, and that an efficient remedy is found, as already indicated, in either turning over or scraping the surface of the filter. The fact brought out that when the sand is unworked the fats slowly oxidize indicates either that the total filter area for any given case should be large enough to admit of a portion of the filter resting occasionally for a few months, or that the sand, if removed, can after a while be again used, although it is probable that ultimately it would require washing in order to remove slight accumulations of silt material carried in suspension by the sewage.

Perhaps as important experiments as any are those relating to the mechanical condition of the filtering materials. As assisting study in this direction, the modern systems of mechanical analysis have been of great value. Indeed, we may say that the recent work along this line has largely given an entirely new phase to all agricultural questions relating to the condition of the soil. In addition to the work on mechanical composition of the sands used in filtration as accomplished at the Massachusetts experiment station, chiefly by Mr. Allen Hazen, similar questions have been studied at the agricultural experiment stations of South Carolina and of Maryland by Prof. Milton Whitney.[1] The studies of these two gentlemen have added greatly to our

[1] See the Second Annual Report of the South Carolina Agricultural Station and the Fourth Report of the Maryland Station; also, as regards methods of making mechanical analyses of soils for filtration purposes, Twenty-second Annual Report of the Massachusetts State Board of Health.

knowledge of this subject, although the earlier work of Hilgard and Johnson is classic.

In order to estimate the filtering capacity of any given material, it is important to understand the air and water capacity of the filtering material when drained, the term "water capacity" being taken to designate the amount of water retained in the interstices after thorough draining. The efficiency of the filtering process depends largely upon these two elements. The amount of water will depend not only upon the closeness of the packing, but also upon its uniformity, and at any given time upon the amount of organic matter stored from the material filtered. The water capacity will also depend largely upon the size of the particles, the finer sands holding much water, especially at the bottom, while with coarse sand the amount held will be nearly constant from top to bottom.

Studies have been made as to the limitation of the size of single doses of sewage. With very coarse material the amount of sewage which can be applied at any one time is limited by the slight retentive capacity, the addition of too large a quantity leading to passage through the filter in too short a time. The conclusion from the studies is that the single dose should not exceed the water capacity of the material, because, if it does exceed such limit, a portion will pass through at once, first forcing out the water previously held, leaving the filter before complete purification can take place. If the air limit is exceeded, the oxygen in the filter is liable to be exhausted before the oxidation is complete.

As to the purification attained by intermittent filtration, the Massachusetts experiments show that very high degrees are reached easily. By way of illustrating the matter, we may simply state that sewage has been purified to the extent of removing from 95 to 99.5 per cent of the polluting material. Sewage containing from 500,000 to 1,000,000 bacteria per cubic centimeter has been so far purified of bacteria that the effluents have frequently contained as few as from 25 to 100 bacteria per cubic centimeter. In order to appreciate this degree of bacterial purification, we may consider that well waters in common use frequently contain from 2,000 to 3,000 bacteria per cubic centimeter. As regards chemical and biological considerations, there is therefore no reason why such sewage effluents are not fit to drink.

The body of information in regard to sewage purification by intermittent filtration which is presented in the several reports of the Massachusetts State Board of Health has become so extensive that one must be an expert to keep in mind the many interesting and valuable results brought out. As assisting the general reader, who may not care to travel through the several thousand pages of matter given in these reports, reference may be made to a very excellent summary of *the results obtained* from intermittent filtration during seven years' *experimentation* at page 497 of the report of 1894, where may be found

brief statements of yearly averages of the various kinds of filters experimented upon, as well as an outline of the most important features in the operation of each filter.

The subject of intermittent filtration has been discussed here because its theory of action applies to sewage irrigation as well, the chief difference between the two being in the method of application and in the agricultural results obtained. We shall see, however, that the two run together, crops being easily raised on filtration areas and the fields of sewage farms frequently irrigated when no crops are growing. The discussion of the theory of intermittent filtration is in reality, therefore, a general discussion of the theory of sewage irrigation. We shall see also that the agricultural utilization of sewage to the best advantage involves the use of intermittent filtration as an adjunct of broad irrigation.

IRRIGATION.

Ordinary irrigation, which consists in the application of water to the soil, in order to assist the growth of plants, has been practiced from the earliest days in Assyria, India, China, Egypt, Italy, France, Spain, and portions of England. Sewage irrigation, on the contrary, is, so far as known, a modern development. It has for its purpose the purification of the water which has been employed in carrying away the refuse of towns. The methods of applying sewage water do not differ greatly from those used in ordinary irrigation, except that by reason of the quality of the material which sewage water carries in suspension and solution special attention to the detail of the process is required, in order that the sewage water may not come in direct contact with the growing plants.

In selecting ground for a sewage farm account must be taken of the relative elevation of the farm and of the town, manufacturing establishment, or residence from which the material comes. Whenever possible, as a matter of economy, the farm should be selected with reference to the sewage reaching it by gravity. If, however, the location does not admit of such procedure, pumping may be resorted to, although this frequently will entail considerable additional expense in first cost of plant as well as in the annual outlay for operation and maintenance. In some cases, where land can be reached by gravity by going considerable distance or can be reached by pumping within a short distance, carefully prepared estimates, taking into account all the elements of first cost, as well as the annual cost of maintenance and operation, may show that it is cheaper to deliver the sewage a long distance by gravity than a shorter distance by pumping.

Formerly it was also considered important to select a sewage farm with reference to the surrounding inhabitation, because there was a prejudice against such farms on account of the assumed liability to effluvium nuisance. This objection has much less weight now than it formerly had, *because* experience has fully demonstrated that with

proper management a sewage farm is no more objectionable on account of bad smells than any other form of farming. The odor of manure is unpleasant, although not specially unhealthful. Undoubtedly there are many barnyards, both in town and country, which are more unpleasant to the sense of smell than well-regulated sewage farms. We may conclude, therefore, in the light of present experience, that an objection to sewage farms on account of serious effluvium nuisance is not well founded. We may further consider that all sanitarians agree that the proper place for disposing of such town refuse is on land. When applied there with due reference to our present information as to the nitrifying process, there is no reason for the production of specially bad smells.

For the best results the topsoil of a sewage farm should be of a

FIG. 4.—Distributing channel on the Berlin sewage farm.

permeable character, with a gravelly or sandy subsoil. If it be compact clay, the sewage can not enter, and the only purification attained will be that due to coming in contact with the soil by flowing over it. Clay soils, therefore, are not so satisfactory for sewage farming as open, gravelly soils, although, as we shall see in describing the sewage farm at Wimbledon, England, it is possible to so treat the sewage and prepare the farm as to attain a very high degree of purification even with clay soils, but the chance of doing this at a commercial profit is exceedingly small.

If not naturally level or of very uniform slope, a sewage farm for *the best results* should be leveled, so that the sewage may flow equally

over every portion. It should also be laid out with distributing channels, as shown in fig. 4, having a proper inclination in order to deliver the sewage readily to all parts of the farm. Formerly it was considered necessary that the carriers be lined with earthenware, concrete, or other impervious material, to prevent the sewage sinking into the ground during its passage along them, but now the more ordinary practice is simply to make earth ditches, with flat slopes. Fig. 5 illustrates a common form of pipe distribution. As to the best size of the field for irrigation, everything depends upon the quantity of sewage to be disposed of and the character of the soil. On this point the advice of a person of experience in sewage farming will be especially valuable.

As to the difference in soils for sewage purification, we may refer to some opinions expressed nearly thirty-five years ago. In 1862 a Parliamentary committee, known as the Select Committee on Sewage of Towns, took a large amount of evidence and reported at length in

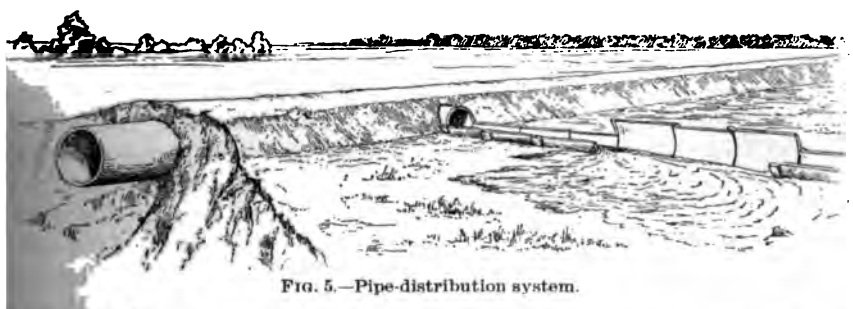


FIG. 5.—Pipe-distribution system.

regard to the agricultural utilization of sewage. Among other eminent authorities called before this committee was Dr. Augustus Voelcker, at that time one of the leading agricultural chemists of England, who testified that sewage could be applied with great advantage on light, porous soils, and, indeed, on all soils which resemble in character such land; but on heavy clay land it could not be applied with advantage, especially when the cultivation was such as to produce in dry weather cracks in the clay, through which the liquid might penetrate to some depth in the soil.

Prof. J. T. Way, another eminent chemist, stated before the same committee that, though valuable materials were contained in sewage, they were coupled with a condition as to constant use in all weathers and at all times which obliged one to limit the use of them, and that if iron pipes were laid over a farm and the farmer given the privilege of using sewage when he liked to apply it, leaving it unused so far as the growing crops were concerned when not needed, there would be no doubt as to the value of sewage in agriculture.

Professor Way also said that under given conditions sewage is of immense value merely as water for irrigation purposes, while under

other conditions—for instance, in times of great rainfall—the water is so objectionable that one might better lose the manure than to be obliged to have the water. These opinions of thirty-four years ago are given here for the purpose of showing that even in the early days of sewage farming it was recognized that the necessity of caring for large amounts of water at all seasons might be a serious burden upon the success of such farming in a commercial way. The development of intermittent filtration since that time has, however, given us more thorough control of all the conditions than existed in 1862.

From our present understanding, the proper method of procedure is for towns to provide, where the conditions admit, intermittent filtration areas on which sewage can be cared for and efficiently purified whenever it is not needed for the purposes of agriculture. Such an arrangement will permit of using it under the conditions laid down by Professor Way; that is to say, the farmer may take it when he needs it and let it alone when it is not needed. As thus employed, there is no doubt that sewage irrigation may be made immensely profitable in all parts of the United States. We say all parts, because there is a popular notion that in the eastern part, at any rate, the rainfall is sufficient to meet all the requirements of agriculture. One needs, however, to study the history of irrigation in foreign lands only casually in order to learn that this impression, like many other popular impressions, is only in a moderate degree true. The author is decidedly of the opinion that irrigation occasionally applied, even in the East, would lead to a very great increase in the productiveness of farms.

By way of illustrating the foregoing proposition as to irrigation supplementing the natural rainfall, the conditions in the Po Valley, in the north of Italy, may be referred to. We have here an extensive plain on which irrigation has been practiced for over two thousand years. For 200 miles along the southern base of the Alps the rainfall in the early part of the year is usually sufficient for the spring crops. Later in the season the rainfall is less, but by the use of irrigation a second crop is raised after the first crop is removed in the early and middle part of the summer. In this way the total yield is nearly doubled.

FILTRATION AREAS NECESSARY.

In order to utilize sewage in the manner proposed, it will be desirable for municipalities to construct intermittent filtration areas at the expense of the municipality at large, on which sewage can be purified whenever not required for agriculture. During the season of actual growth, when sewage would be naturally used for irrigation, the filtration areas would be allowed to rest, thus perfectly fulfilling one necessary condition which we have already discussed in treating the subject of intermittent filtration.

Possibly the objection will be raised that under this arrangement *the towns themselves* would not realize a profit on the sewage. This,

FILTER AREAS AT PLAINFIELD, NEW JERSEY.

wever, is not a matter of any moment. The towns, as we have en, really owe it to the riparian proprietors on the streams below e points where sewage enters not to so foul the stream as to create a isance. It is a natural right of the riparian owners to demand that wage pollution be prevented. It is a duty, therefore, on the part towns to purify sewage before allowing it to enter streams. If in e process of such purification the towns can realize even a partial urn, they have so much clear gain; they should look upon it as a rtial recoupment of a necessary expense which otherwise would be ich larger.

Experience has shown that there is no objection to raising crops on e intermittent filtration areas, and on several of the English sewage rms, as well as on those of Germany, this practice is quite common. has also been done at South Framingham, Massachusetts; at Plainld, New Jersey, and at other places in the United States. At South amingham, in particular, the result of several years' experience is indicate that Indian corn grows with the greatest luxuriance upon e filtration areas, so much so that in some years the standing crop is been sold in the field to the highest bidder at as much as from $30 $40 per acre. At the same time the effluent from the South Framingam sewerage works, which flows into the Boston water supply, has en kept up to the proper standard of purity. The works at South ramingham are owned by the town.

OPINIONS OF FOREIGN COMMISSIONS.

Examples of this sort show the importance of approaching questions sewage purification and utilization from a practical point of view, nd with due reference to the recent information as to the effect of the itrifying organism in preparing refuse substances for utilization by lant life. The problem takes on such new forms that much of the old nformation has little application. There are, however, a large number of opinions expressed in the past by government commissions and minent sanitarians which are considerably enforced by the recent iews. Let us refer a little in detail to several of these opinions hich have been shown by the passage of time to be fundamentally ound. In 1857 a commission [1] was appointed to inquire into the best ode of distributing the sewage of English towns and applying it to neficial and profitable use. This commission included among its

[1] Sewage of Towns Commission, Reports 1, 2, 3, 8°, London, 1858-61-65. These reports contain details of careful investigations. Elaborate cultivation and feeding experiments were purd extending over a period of several years, the results of which were presented in great ail in the second and third reports. In the appendix to the first report may be found an count of a visit made by a committee of the commission to Milan, Italy, for the purpose of amining the sewage utilization works at that place. This committee reported, under date of cember, 1857, that the experience of the irrigation around Milan added a striking proof to at already obtained as to the value in agriculture of a command of pure water, and of the mense increase of that value obtained by the addition of sewage combined with the higher nperature derived by the liquid in its passage through the town.

members such eminent engineers and chemists as I. K. Brunell, Robert Rawlinson, Prof. J. T. Way, J. B. Lawes, John Simon, and Henry Austin. They studied the question in all its phases and carried out extensive experiments, which are detailed at length in their reports. In the final report, presented in 1865, the commission said that as a result of its labor and investigation it was of the opinion that the right way to dispose of town sewage is to apply it continuously to land, and that the pollution of rivers can be avoided only by such application; that the financial results of applying sewage to land differ under different local circumstances, because in some places irrigation can be effected by gravity, while in others pumping must be employed; also, because heavy soils, which may be alone available in some places, are less fit than light soils for sewage irrigation. The commission also expressed the opinion that where local circumstances are favorable, and undue expense is avoided, towns may derive profit from applying sewage in agriculture.

As a final summation, this commission states that wherever rivers are polluted by the discharge of town sewage into them, the towns may be reasonably required to desist from causing a public nuisance.

In 1865 another commission was appointed (referred to on p. 19), commonly known as the First Rivers Pollution Commission. It consisted of Robert Rawlinson, J. T. Harrison, and J. T. Way, who were charged with an inquiry as to how far the use of rivers and running waters in England for the purpose of carrying off the sewage of towns and populous places and the refuse arising from industrial processes and manufactures could be prevented without risk to the public health or serious injury to such processes and manufactures, and how far such sewage and refuse could be utilized other than by discharge into rivers or rendered harmless before reaching them.

In its report on the River Thames this commission suggests that the whole river be placed under the superintendence of one governing body, and that, after the lapse of a period to be allowed for the alteration of existing arrangements, it be made unlawful for any sewage, unless the same has been passed over land so as to become purified, or for any injurious substances or refuse from paper mills, tanneries, and other works, to be cast into the River Thames between certain limits defined in the report, and that any person offending in this respect be made liable to penalties to be recovered summarily. In their report on the River Lea the commissioners suggest that a similar arrangement be made for the more thorough control of that stream.

In 1868 the Queen's commission was issued to what is known as the Second Rivers Pollution Commission, whose work in the line of intermittent filtration has been referred to on pages 29 to 31. The scope of this commission's inquiry, as given on page 29, is seen to be the same as that of the First Rivers Pollution Commission. The Second Rivers *Pollution* Commission studied questions of sewage purification very

broadly, making six reports in all, which are the great mine of information as to river and stream pollution at this day. As regards these particular subjects, in no civilized country has work approximating to that of the Second Rivers Pollution Commission been performed.

In the summary to the fourth report, on the best means of preventing the pollution of rivers, the commissioners take the ground that the question of how to prevent polluting liquids from gaining access to running water could not be successfully answered without first defining just what is meant by polluted water; and that following this line, for the purpose of efficient legislation, an arbitrary line should be drawn between waters which are to be deemed polluting and inadmissible into streams and those which may be considered innocuous and therefore admissible to streams. The commission therefore gives certain standards of purity, which it is not necessary to reproduce, and states that such standards have been formed with the most careful regard for the interests of both towns and manufacturers. It expresses the opinion that the adoption of the methods proposed would not inflict any injury on manufactures, but might, on the other hand, save the manufacturers from inflicting injuries upon themselves. It is also pointed out that one of the most crying evils in manufacturing districts is the want of clean water, and that therefore every successful effort to make dirty water again usable is a clear gain to the manufacturing class as a whole.

In 1876 the English Society of Arts took up the study of various subjects connected with the health of towns, and, as an authoritative scientific society of the country, appointed a committee to report to the society in regard to the various questions involved in sewage utilization and the allied sanitary subjects. In its report the committee states as its opinion that where land at a reasonable price can be procured with favorable natural gradients, with soil of the proper quality and in sufficient quantity, a sewage farm, if properly conducted, is apparently the best method of disposing of water-carried sewage.

The committee also cautions the reader to bear in mind that a profit need not necessarily be looked for by the locality or municipality establishing the sewage farm, but that the farmer may be expected to reap profits from the operation. As to the sludge from precipitation processes, it is pointed out that from the manurial point of view it is of low and uncertain commercial value; that the cost of its conversion into a valuable manure will preclude the attainment of any adequate returns for the outlay and working expenses connected therewith, and that means must therefore be used for getting rid of it without reference to possible profit.

In 1882 the Queen's commission was again issued to what is known as the Royal Commission on Metropolitan Sewage Discharge. The scope of this commission's inquiry has been already referred to on

page 31, in our discussion of intermittent filtration. This commission reported that it was neither necessary nor justifiable to discharge the sewage of the metropolis in its crude state into any part of the River Thames, and that some method of precipitation should be used to separate the solid from the liquid portions of the sewage. As a preliminary and temporary measure, however, the liquid portion of the sewage remaining after the precipitation of the solids might be suffered to flow into the river at a period between high water and half ebb of each tide, and at no other time.

It is also strongly stated that the liquid so separated would not be sufficiently free from noxious matters to allow of its being discharged at the present outfalls as a permanent measure; it would require still further purification, which, according to present knowledge, could be accomplished efficiently only by applying it to land. Because of the difficulty of obtaining sufficient area for irrigation in the vicinity of London, the commission was of the opinion that this additional purification could be best effected by intermittent filtration, for which, from the information at hand, it was concluded that sufficient area was available, at any rate within convenient distance of the northern outfall. As to the southern outfall, the commission was unable to state from its investigations the quantity of available land; in case of insufficient land available, the clarified effluent of the southern outfall was to be conveyed to the north side by a conduit under the river.

In 1892 the Queen's commission was again issued to what is known as the Royal Commission on Metropolitan Water Supply,[1] which was charged with inquiring into the present source of supply of the metropolis and as to whether the quality and quantity were adequate, etc. This commission included among its members such eminent sanitarians as Sir George Bartley Bruce, George H. Hill, and James Mansergh. In summing up the matter this commission said that all possible vigilance should be exercised to prevent unnecessary contamination of the rivers Thames and Lea and their respective tributaries, as well as to insure the thorough treatment of all sewage, before it is allowed to pass into the rivers, by the most efficacious methods that experience and science may dictate.

The Royal Commission on Metropolitan Water Supply also remarked that advances had been made during the past twenty-five years in the construction of sewage works in the valleys of the Thames and Lea; that where such works had been constructed on an efficient system the sewage could be so dealt with at all times, except those of flood, that the effluents were clear and innocuous. It should be borne in mind that this opinion is expressed by a commission which included

[1] Metropolitan Water Supply, Report of Royal Commission on, 6 volumes, general report, minutes of evidence, appendices, index, plans, etc., 4°, London, 1893. The most recent and extensive information as to pollution of streams and its effect on the water supply of the metropolis *as applied to the* rivers Thames and Lea, from which that supply is drawn.

in its membership some of the most eminent sanitarians of the present day, and that the streams into which the sewage effluents pass are the sources of the water supply of the largest city in the world.

In 1874 Sir John Hawkshaw was commissioned to inquire as to the pollution of the River Clyde and its tributaries and how far the sewage refuse from the towns and manufactories could be utilized and got rid of without running into streams, etc. In his report it is pointed out very forcibly that those who own and manage manufacturing establishments have them wholly under control, and that they can therefore provide and enforce the necessary provisions and regulations for removing the nuisances which they so often create, and that by reason of this fact there can be no necessity for the fecal matter from such establishments being passed into the streams. He also points out, as has been done by a number of other commissioners, that wherever large populations are gathered and numerous manufactories exist on the banks of any river, combined action should be taken to secure the waters of the stream from pollution as far as practicable. As a mere matter of fairness the manufactories and all works and establishments similarly situated should be treated alike.

In 1875 the president of the English Local Government Board requested Robert Rawlinson and Clare Sewell Read to report to the board as to the several modes of treating town sewage. The report, submitted in 1876, is one of the most valuable contributions to the literature of sewage disposal thus far made. Among the conclusions Messrs. Rawlinson and Read point out: (1) That the scavenging, sewering, and cleansing of towns are necessary for comfort and health, and involve in all cases questions of how to remove town refuse in the safest manner and at the lowest expense. (2) That the retention for any lengthy period of refuse and excreta in private cesspits or in cesspools, or at stables, cowsheds, slaughterhouses, or other places in the midst of towns, must be utterly condemned. * * * (3) That the sewering of towns and the draining of houses must be considered a prime necessity under all conditions and circumstances. * * * (4) That most rivers and streams are polluted by the discharge into them of crude sewage, which practice is highly objectionable. (5) That as far as they have been able to ascertain, none of the existing modes of treating town sewage by chemicals appear to effect much change beyond the separation of the solids. * * * (6) That so far as examined none of the manufactured manures made by manipulating town refuse, with or without chemicals, pay the costs of treatment. * * * (7) That town sewage can best and most cheaply be disposed of and purified by the process of land irrigation for agricultural purposes where local conditions are favorable to its application. * * * (8) That land irrigation is not practicable in all cases. * * * (9) That towns situated on the seacoast or on tidal estuaries may be allowed to turn sewage into the sea or estuary below

the line of low water, provided no nuisance is caused and that such mode of getting rid of sewage can be justified on the score of economy.

The foregoing include the opinions of practically all the leading sanitarians of England for the last thirty-five years, and, as will be seen, such opinion has been unanimous that the preferable mode of purifying town sewage is by application to land. So overwhelming is this evidence that we must, in the future, consider this part of the subject as what the lawyers call res adjudicata—a proposition absolutely settled and no longer to be called into question. The progress of the recent views to which we have already referred has assisted in taking this proposition out of the realm of controversy.

In passing we may remark that similar opinions have been expressed by German, Italian, and French Government commissions; but these latter all fall so entirely within the line of the view taken by the several English commissions that it is unnecessary to cite them here,

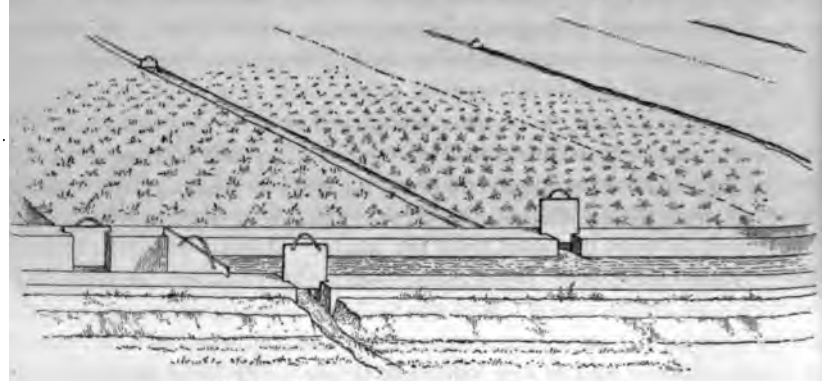


FIG. 6.—Ridge-and-furrow beds, with cropping.

the more especially because, sewage disposal having originated in England, the commissions of other countries have in their reports essentially followed the English views.

METHODS OF APPLYING SEWAGE.

As already stated, the methods of applying sewage in broad irrigation are substantially those of ordinary irrigation, with the exception of the necessity for closer attention to the detail. The principal special systems of irrigation used in sewage farming are known as (1) the ridge-and-furrow or bedwork system and (2) the catchwork system. Great variations from these two systems may, however, allowed.[1]

Figs. 6 to 13 illustrate a number of different methods of applying the sewage. We may also refer to the pipe-and-hydrant system, as

[1]For methods of laying out land applicable to sewage farms, see Les Irrigations, by A. Ronna (3 volumes, 8°). This is the most recent of the French text-books, and treats the preparation of land in full detail.

l as to the level-bed system, used when the filtration areas for rmittent filtration are utilized for raising crops.

ı laying out land for the ridge-and-furrow system a series of slope s are prepared, along the top of which supply carriers are laid, ch are formed with level edges, so that the water flows over in a ı film and so on down over the slope beds with uniform depth. h ridges are made in couples, with the slopes varying from 1 in o 1 in 150. The amount of slope to be given in any particular case

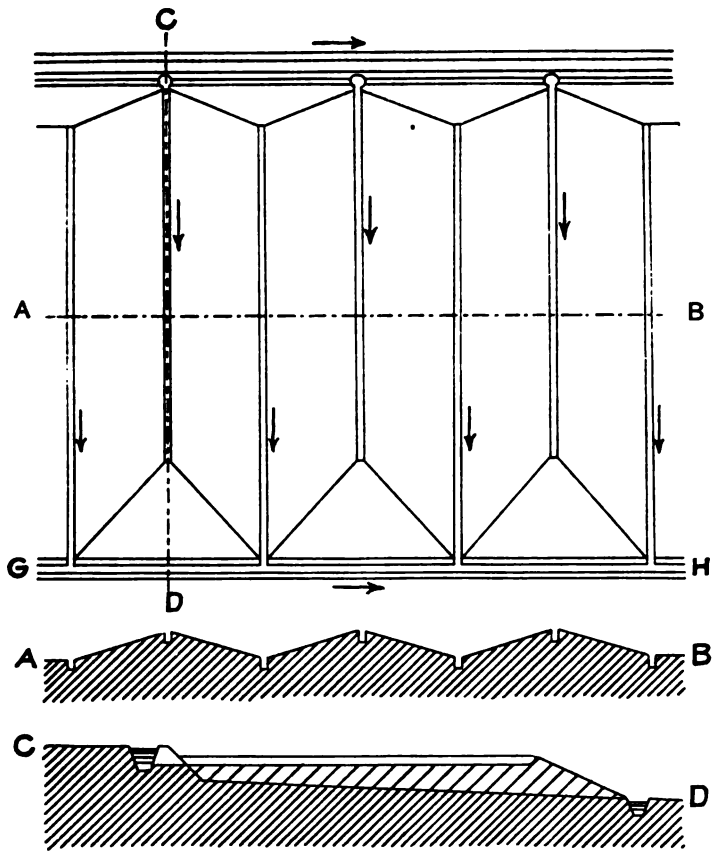


FIG. 7.—Plan and sections of ridge-and-furrow irrigation (Ronna, p. 438).

urely a matter of judgment, in which the controlling factor is the ousness of the ground to be irrigated, the object of the slope being nsure that the water reaches in sufficient quantity all parts of the to be irrigated. Common dimensions of the beds are a total adth of from 30 to 40 feet, or a breadth of slope on each side of the e of from 15 to 20 feet, although in exceptional cases, depending ust the use to which the beds are to be placed, the beds may be le larger. The length may be any convenient dimension suited

to the contour of the area prepared. Land under such beds may be underdrained in accordance with the rules for underdraining which apply in ordinary farming, though in deciding whether or not to fully underdrain any given area it should be remembered that drainage increases the porousness of the soil.[1]

At the foot of the slopes a furrow is formed, which receives any sewage not absorbed in the passage over the beds and conducts it away to another and lower series of beds or to the outfall, as the case may be. Ordinarily the surface water of one irrigation should be passed over several beds in order to insure thorough purification. This is especially important where the beds are made of the sizes indicated in the foregoing. The thorough removal of the water at the

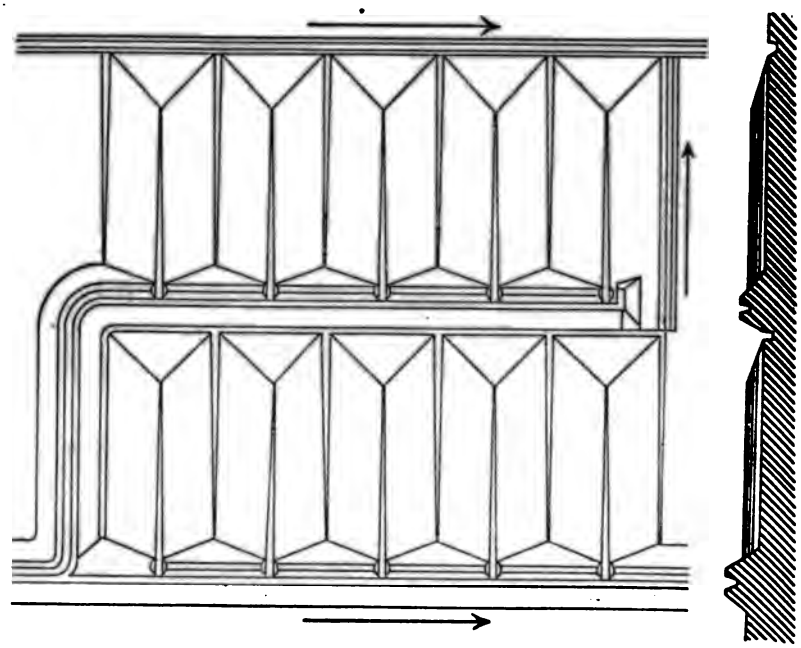


FIG. 8.—Double-bed ridge-and-furrow irrigation, with direct or secondary irrigation on the lower bed (Ronna, p. 449).

foot of the slopes, as well as the prevention of water-logging of the land, is insured by making a furrow at the foot of the slopes of ample dimension and with fall enough to produce quick drainage. Figs. 7 and 8 show the arrangement of the ridge-and-furrow system of irrigation.

In the catchwork system, which is more especially adapted to steep and irregular land, the liquid is delivered at the highest point of the area, the same as with ridge-and-furrow, a main carrier with level lip

[1] French, Henry F.: Farm Drainage: The Principles, Practice, and Methods of Draining Land, etc., 12°, New York, 1884. Waring, Col. George E., jr.: Draining for Profit and Draining for *Health, 2d ed.*, 12°, New York, 1883.

on the lower side, along the highest contour, permitting the irrigation water to overflow the edge when dams are placed temporarily at various points on its course. At some distance lower down a catch gutter is formed on the contour, into which the unabsorbed overflow of the main carrier is caught as it flows downward. A damming of the catch gutter at suitable intervals causes it to overflow to the second, the same as in the case of the main carrier, and so on down to

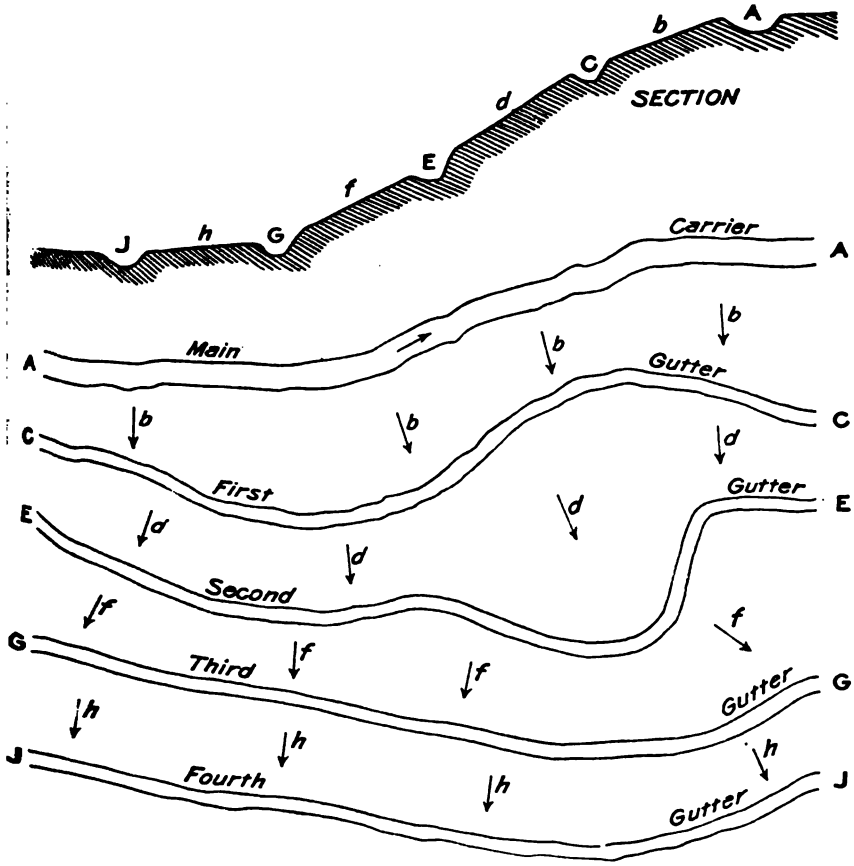


FIG. 9.—Catchwork system of irrigation.

the lowest contour of the area irrigated. The detail of this operation is illustrated by fig. 9.

According to Mr. Burn,[1] the great difference between the ridge-and-furrow system and the catchwork system is in the laying out of the ground. In the catchwork system, although the natural inclination of the ground is taken advantage of in the most direct and simple manner, still a considerable inclination is necessary for its successful application. The ridge-and-furrow system, on the other hand, is

[1] Burn, R. Scott: Outlines of Modern Farming, 6th ed., 12°, London, 1888. Treats extensively, among other subjects, of the utilization of town sewage, irrigation, etc.

more especially applicable to flat ground, such as is usually found valleys or along the banks of rivers. In this system the necess inclination is given by artificially throwing up the ridges, and skill with which one part is taken advantage of to make up the d ciencies of another part will determine the degree of economical s cess. Generally speaking, the catchwork system is much chea than the ridge-and-furrow system, and at the present time the rid and-furrow system is only used where the ground is exceedingly or where for some special purpose the catchwork system is deemed be specially undesirable.

Mr. Burn calls attention to certain points to be observed in l ing out beds for the ridge-and-furrow system, as follows: If la

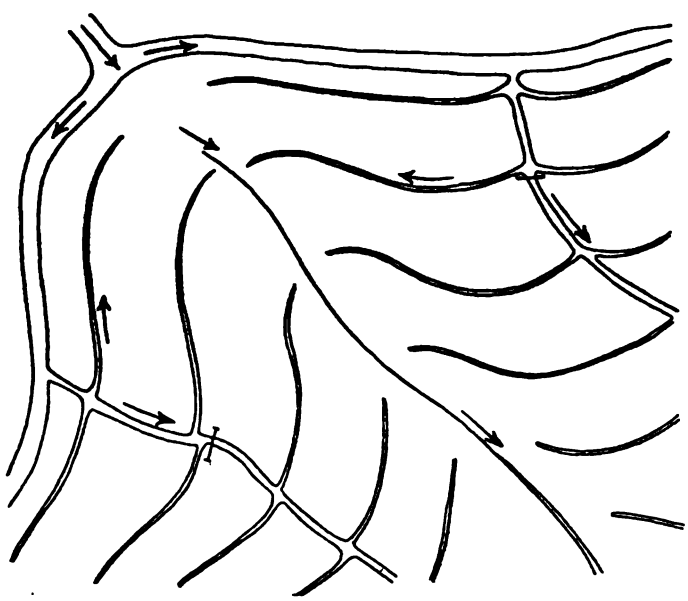
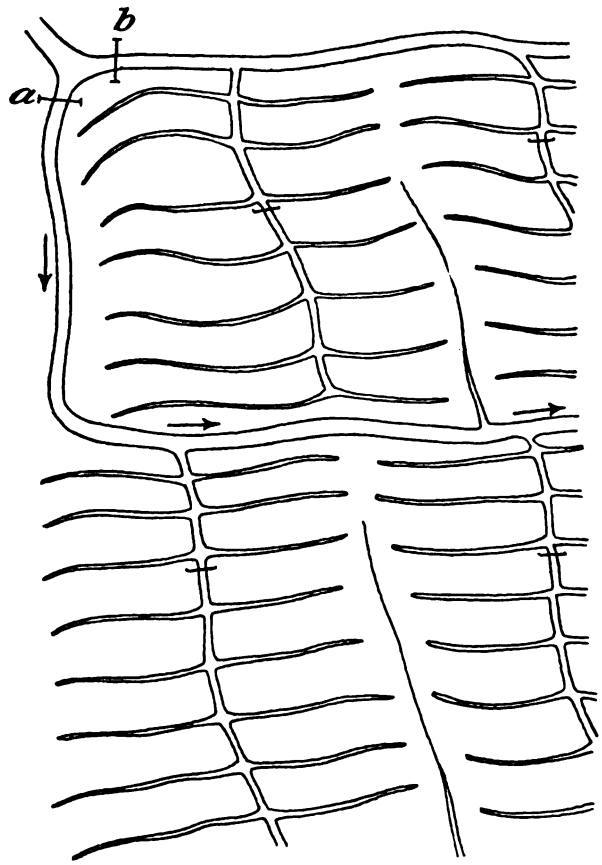


FIG. 10.—Distribution system adapted to irregular land (Ronna, p. 382).

intended for permanent meadow has a covering of sod, this should removed by cutting into strips some 15 or 18 inches wide and plac carefully at one side. The inclined beds should next be made s the levels properly adjusted; then the channels of supply and drains for leading off the water when used should be marked Cutting out of these may then be proceeded with, taking care beginning the leading channels of supply that the soil taken out fr these and the drains be carefully spread over the inclined surfa After the channels are all cut, if the ground is to remain down meadow, the turf may be replaced. This work should be done w care in order to prevent irregularities of the surface. In all this w the point to be observed is that all parts of specially prepared surf *shall receive* their due supply of sewage. If hollows are left,

ge will be likely to collect therein and become stagnant. Mr. expresses the opinion that the objections which have been fretly raised to the rankness of sewage-grown grass have had their n chiefly in the badness of the plan adopted for applying the ge. If this is true, it is obvious that the small additional expendnecessary to prepare the ground properly will be repaid.

to the relative costs of preparing land for ridge-and-furrow irrin, it has cost in England, in some cases, as much as from $100



3. 11.—Double system of contour distribution controlled by end gates (Ronna, p. 395).

50 per acre, while catchwork systems have been carried out for $10 to $25 or $30 per acre. The difference in price alone would to the use of the catchwork system and modifications of it in country.

a pipe-and-hydrant system of distribution a series of pipes is laid ding to such a system (depending upon the topography) as will t of reaching every point of the area to be irrigated with sewage. ierly iron pipes were used for this purpose, but at the present

time terra-cotta or vitrified tile pipes are quite commonly used. In order to render the irrigation of the field as convenient as possible, hydrants are placed at proper points, fitted with the usual coupling for connecting hose. Sewage is forced through these pipes, either by steam power or gravitation, as the case may be, and distributed to the surface of the fields by means of hose.

In a gravitation system a receiving tank is usually placed at a convenient elevation above the area to be irrigated, from which mains are laid to different parts of the irrigated area. In such a system the power with which the sewage flows from the hydrants is necessarily fixed by the height of the tank, but in a pumping system the power can of course be varied the same as in any other application of pump-

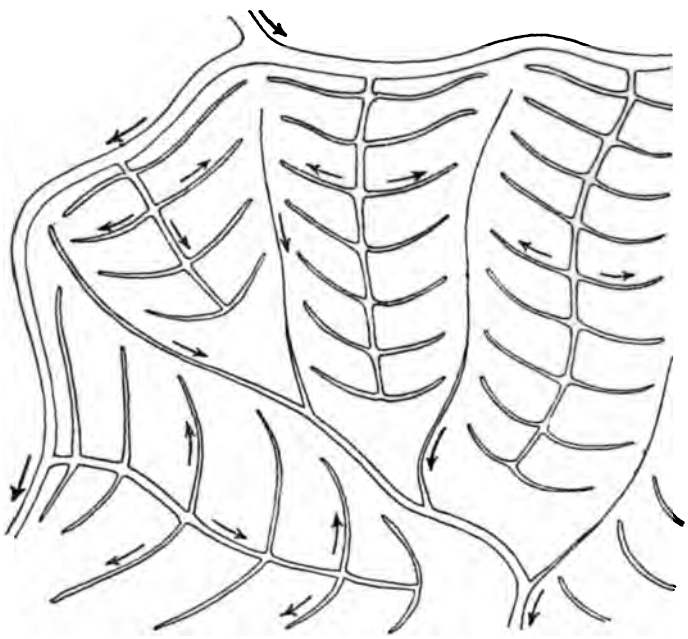


FIG. 12.—Distribution adapted to irregular ground (Ronna, p. 399).

ing. The detail of arranging such systems can not be given except in a very general way, because of differences in local conditions, but it will readily present itself to any engineer skilled in this class of work when the necessary preliminary data are placed before him. In England a large number of pipe-distribution systems have been carried out, while in this country the distribution at the Pullman, Illinois, sewage farm is effected in the same manner. The scarcity of water in southern California has also led to a considerable use of pipe systems there for the distribution of ordinary irrigation water, especially in the vicinity of Los Angeles.

One of the most complete systems of this kind is on a sewage farm at Rugby, England. This was established by Mr. G. H. Walker, who

tered into an arrangement with the borough of Rugby to take the wn sewage, which at the time of laying out the farm amounted to out 160,000 gallons a day. All cesspools were abolished in the town, d even the humblest cottage was provided with water-closets, so at the entire refuse of a population of 7,000 was delivered into the wers.

The sewage flows from the town into an open brick reservoir 50 et in diameter and 12 feet in depth, from which it is forced by steam essure into a system of cast-iron pipes led over the farm. The

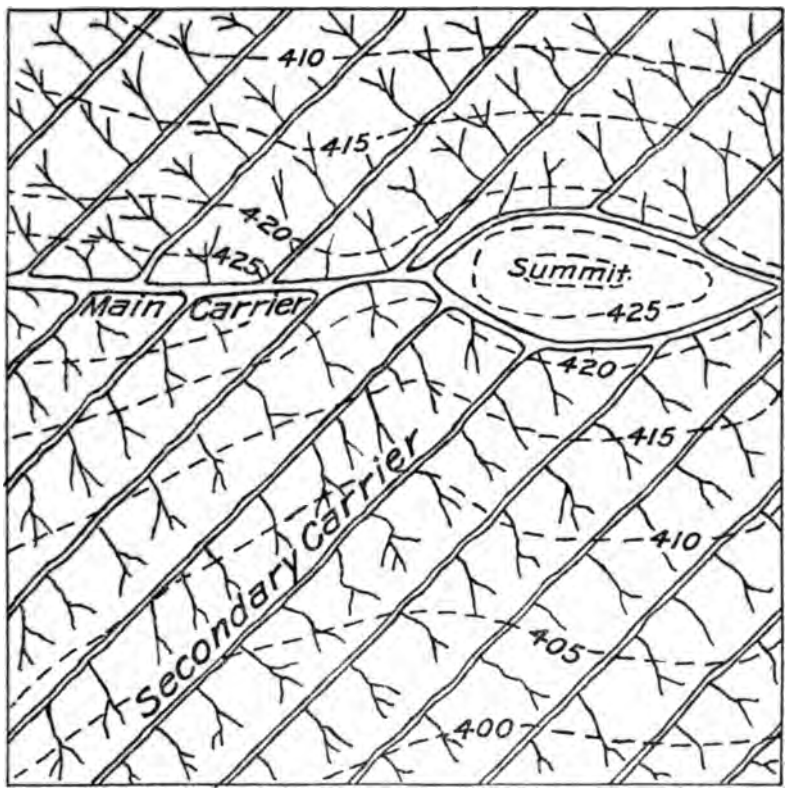


FIG. 13.—Distribution adapted to a field with ridge.

eatest elevation to which the sewage is pumped is about 60 feet ove the reservoir, although a considerable portion of the land is er 20 feet above that level, and some of it as much as 20 feet low. The engine works a small air pump for the purpose of agi- ing the sewage in the receiving reservoir and preventing the posit of solid matters.

The distributing pipes are laid over 420 acres of land, chiefly in ass, and comprise about 5½ miles, or about 691 feet per acre. The ain distributary is 6 inches in diameter, with branches 3 inches in ameter. The total number of hydrants is 66, fitted with couplings

for attaching hose from time to time to distribute the sewage in the neighborhood of each. The works originally cost about $32 per acre, but with the experience gained from these and other works it is believed that similar works could now be carried out for $25 or less per acre. Probably, by the use of terra-cotta pipe for that portion of the distribution system not required to take high pressure, the cost

FIG. 14.—Section of intermittent filtration area.

of such a system, with favorable topographical conditions and a large area, could be brought within $15 to $18 per acre. The cost of distribution is stated at not exceeding 1 cent per ton of sewage.

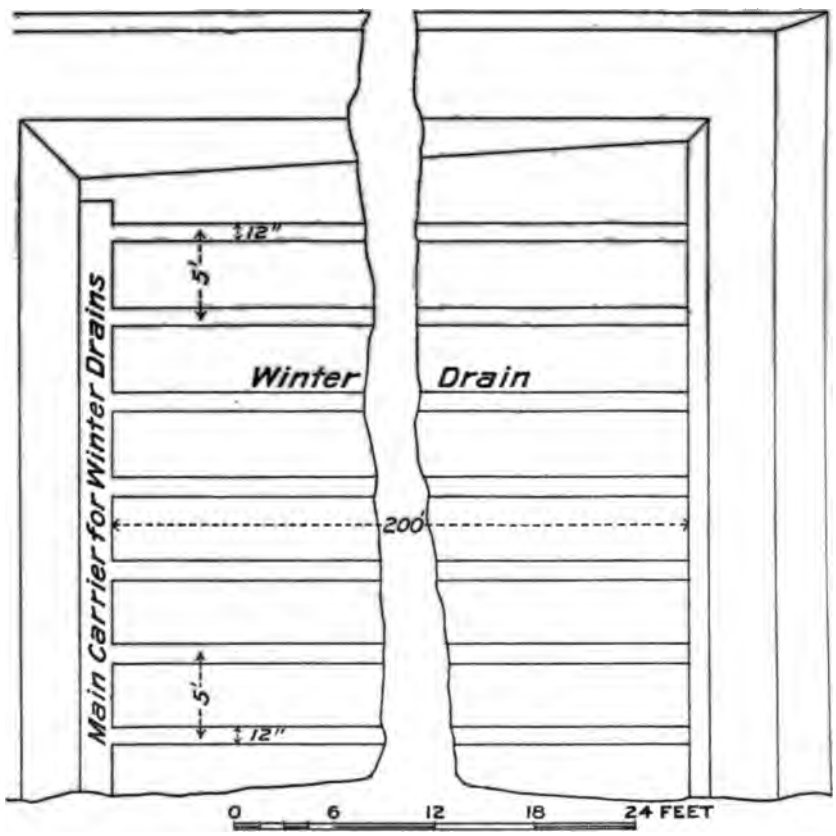


FIG. 15.—Plan of arrangement of winter drain on a filter area with absorption ditches.

In preparing intermittent filtration areas for the growth of crops level filter beds are made with low embankments around them, the area varying according to local conditions from 1 to 4 or 5 acres. Carriers are run on convenient lines for supplying sewage to these beds at suitable intervals. The area is also thoroughly underdrained, with *the drains laid* at least 5 feet deep. In some soils a slight advantage

l be gained by making the drains as deep as 6 or 7 feet. In order grow crops upon such areas the surface is prepared with a series absorption ditches, where the sewage is allowed to stand until it ks away into the ground, the length of time required for its dis-pearance of course varying according to the permeability of the l. Absorption ditches are illustrated by figs. 2, 3, and 15. On an sands, as experimented with at the Massachusetts experiment tion, it was found that very large doses of sewage would sink into arse sands in a very few minutes, but in fine sands, especially after ey had been a long time in use, the period is considerably prolonged. some cases it may be as much as twenty-four hours, the depth of wage applied of course entering in as a controlling element.

If it is desired to dispose of sewage on filtration areas fitted with

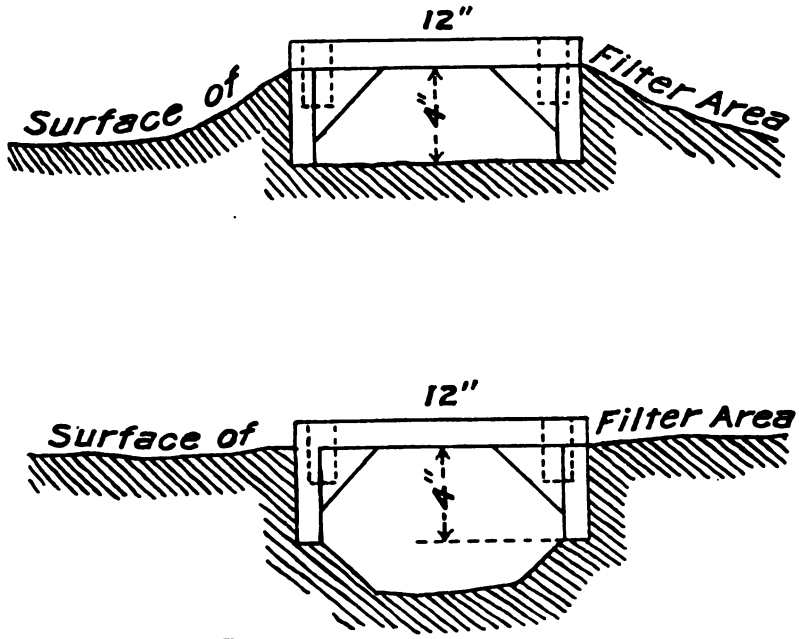


FIG. 16.—Cross section of winter drains.

sorption ditches during the winter season in extremely cold climates ible to heavy snowfall, and a high degree of purity of effluent is quired, the ditches may be covered with boards, somewhat in the anner already described for the experimental sand-trench area at wrence. Where a lower degree of purity of winter effluent is suffi-nt, the areas may be left without any covering at all. Experience s shown that the sewage, by reason of reaching the fields at a tem-rature considerably above freezing, will penetrate beneath the snow, ilm of ice freezing on the under side thereof and the process of filtra-n going on the same as if the snow were absent, except that the low nperature will tend to decrease the activity of the nitrifying organ-ns. This case, however, is provided for in a natural way. As shown

by the experiments, the tendency in winter is for the nitrogenous matter to store itself in the sand by what in effect is a process of simple straining. As warm weather comes on in the spring, nitrification again resumes its sway, with the result of finally resolving the stored matter of the cold period. We have here a very interesting illustration of the fine balance of forces sometimes existing in nature. The nitrifying organisms, by reason of susceptibility to temperature, are enabled to carry on their work more actively in warm weather than in cold. The soil, acting as a simple strainer, strains out the objectionable matters in cold weather and stores them up until the period of activity of the nitrifying organisms shall have again come round, when these minute agents again successfully perform their appointed work.

BEST CROPS FOR SEWAGE FARMING.

A large amount of study has been directed toward the question of the best crops for sewage farming, especially in England, with the result of showing that in that country, at any rate, almost any crop which can be raised in ordinary farming can be cultivated on properly managed sewage farms with good effect. Among the crops ordinarily raised we may mention Italian rye grass, seeds, pasture, potatoes, wheat, oats, barley, mangolds, carrots, cabbage, parsnips, turnips, beans, rhubarb, celery, peas, lettuce, and corn. In southern climates the yam has been grown to good effect with sewage irrigation, while in southern California, orchards are successfully irrigated with sewage. The species of water willow known as osier is also grown extensively on sewage farms, not only because it is a valuable crop in the vicinity of towns, where it is extensively used in basket making, but especially because it has the property of absorbing large quantities of water. The American water weed, anacharis, is also a very gross feeder and will assimilate large quantities of organic impurity. Among other water plants which are capable of absorbing organic impurities may be mentioned duck weed, sedges, common reed, flowering rush, water lilies, liverwort, water cress, etc. There is, however, no special advantage in using some of these so long as plants having commercial value can be raised.

At the Doncaster sewage farm in England, in addition to wheat, barley, oats, rye, potatoes, rye grass, clover, meadow grass, and osiers, considerable quantities of small fruits, such as currants, gooseberries, and raspberries, have been successfully cultivated. At Berlin the chief crops are rape grown for seed to be used in the manufacture of oil, colza, mustard, carroway, hemp, and the cereals—wheat, rye, barley, and oats—with potatoes, beets, turnips, cabbage, and vegetables generally.

In the irrigation on the Plain of Gennevilliers, at Paris, by reason of the nearness of the fields to the city of Paris, the crops produced are chiefly those common to ordinary French truck farming. As we

see farther on in discussing the Paris irrigation problem, very
ble success has been attained here in the raising of all ordinary
en truck. Undoubtedly, however, the keeping of a large amount
e stock and the production of beef and dairy material is, on the
e, the most important branch of sewage farming. Italian rye
in suited above all other grasses for irrigation, and in England,
and, and other countries yields, with sewage irrigation, prodi-
crops of forage of best quality. Under favorable conditions it
ielded as much as 60 tons of green forage per acre per year. In
count of Italian rye grass which appears in Bulletin No. 73 of
North Carolina experiment station it is stated that Italian rye
is scarcely hardy north of Washington, but is fully hardy in
Carolinas; that it resists drought well, but requires for the best
ts a deep, moist, rich soil. On poor soils it is stated to be of lit-
alue. The growth is upright, 2 or 3 feet high, and very leafy.
ich soils it should be cut every three or four weeks, as otherwise
eavy growth is apt to cause the grass to lodge and rot at the base
e culms. This grass shoots early in the spring and flowers in
When grown for seed, it yields as much as 300 to 400 pounds
cre, worth from 3 to 5 cents per pound.

glish perennial rye grass, the seed of which is quite similar to
of Italian rye grass, is also grown extensively in England, where
nstitutes the chief grass of many of those famous pastures which
not been broken up or reseeded for over a century. It forms a
thick, compact turf, which is not easily broken by the feet of
als. This grass may be grown on the heavy clay soils of the
h, but is not considered as fitted for the conditions of agriculture
e North.

e seed of the English perennial rye grass is much less expensive
that of the Italian rye grass, and hence is frequently used as an
terant of the latter. The seeds of such weeds as are common to
neadows are also frequently largely present in uncleaned samples
ye-grass seed. For these several reasons the Italian rye-grass
should be purchased only of reputable dealers and under a
anty of quality. A bushel weighs from 18 to 24 pounds. When
alone, it requires from 45 to 50 pounds per acre.

lletin No. 73 of the North Carolina agricultural experiment station
states that Italian rye grass is one of the best grasses for temporary
on good moist soil. It is best sown alone or with alsike clover. If
in the fall, it will give five or six heavy cuttings in the succeed-
ear, and is best plowed up the next fall. If sown in the spring,
ay be allowed to stand the second season. This grass has often
used in small quantities in mixtures to serve as a nurse for the
permanent and vigorous species, but it is now generally agreed
this is not the best practice, as the luxuriant growth of the rye
is likely to smother out the grasses it was meant to assist. It

disappears at the end of the second year, leaving the ground unoccupied for weeds to come in. Italian rye grass is stated as very exhausting to the soil, and hence becomes especially amenable to irrigation by sewage. According to the experiments of the English Sewage of Towns Commission, as well as the practical observation of farmers who have tried it in the South in this country, its value for feeding is very high. When grown in the South, in ordinary farming, it is necessary to reseed it every second year; but probably with sewage irrigation it could be carried to the third year, the same as the ordinary practice in English sewage farming. At the Berlin sewage farm, where a considerable quantity of Italian rye grass is grown, the best mixture has been found to be timothy and rye grass, about half and half.

Clovers and alfalfa are also crops which have been found to thrive well on moderate sewage irrigation at different places, especially the latter. This will grow in favorable soil anywhere from about sea level to 7,000 feet elevation. It may be seen very commonly in the valleys under the foothills of the Colorado and California mountains. It grows best in a light, rich, sandy loam, underlain by a loose, permeable subsoil, and its development is considerably influenced by such conditions as the depth and warmth of the soil, the depth of the ground water below the surface, and the physical character of the subsoil generally. Its cultivation has been most successful in the arid regions of the West and Southwest, where, because of the light rainfall, an artificially controlled water supply is commonly used. Experience there indicates that it grows better under irrigation than under any other conditions, as in this way the quantity of water exactly suited to its best development may be supplied. Good drainage is necessary, as otherwise the plants are likely to be killed by an excess of water either in the soil or on the surface. When undergoing irrigation, water should not be allowed to stand on the alfalfa field more than forty-eight hours, as otherwise the ground becomes saturated and the plant liable to be drowned out. A very complete account of alfalfa may be found in Farmers' Bulletin No. 31 of the United States Department of Agriculture.

Before the modern application of the practice of ensilage to the preservation of green crops came into use one great difficulty in the management of sewage farms related to the disposition of the enormous green forage crops which sewage-irrigated land produces. With ensilage, however, this difficulty is entirely done away with, and sewage farming may be considered to have taken by its use a new impulse. Most of the reiterated objections of from twenty to twenty-five years ago as to the impossibility of operating sewage farms at a profit have been removed, and, indeed, ensilage is another recent new application through which sewage farming may be said to have taken on such entirely different lines of development as to render *many of the* discussions of an earlier date of little value.

In eastern countries silos have been used for preserving corn for many hundred years. Underground pits are stated to have been used by the wandering tribes of Arabia in order to prevent victorious enemies from obtaining possession of food supplies. The Moors brought the art of ensilage into Spain, whence it found its way into France and Germany, and finally extended to England and the United States, in which latter countries its use has mostly grown up since about 1880.

As to the theory of ensilage, it may be remarked that if green crops are left exposed to the air for any considerable space fermentation begins, and if left unchecked will continue until putrefaction sets in and the crop becomes useless for feeding purposes. It is now understood that fermentation is produced by the active agency of bacteria. According to the researches of Pasteur there are certain ferments which continue their action without the presence of oxygen; such fermentation is called putrefaction, and is accompanied by the production of bad odors. It is the opposite of nitrification, which takes place only in the presence of oxygen, and is, when working to the best advantage, entirely unaccompanied by odor.

Again, all putrefactive fermentation is accompanied by the production of considerable quantities of heat. If we place a green crop in the silo, but leave it freely exposed to the air for a few days, it becomes heated to a temperature of from 125° to 150° F., at which point the bacteria are killed and the subsequent fermentation which would otherwise have been produced by them is arrested. The material so produced is called sweet silage, which remains aromatic by reason of having gone through merely what is called hay fermentation.

When, however, the green crop is put into the silo and subjected to pressure, with the exclusion of air immediately after being put in, the temperature does not rise above about 100° F. At this point the bacteria are not killed and the fermentation proceeds to the point of forming lactic or acetic acids, the process being accompanied by the loss of some of the saccharine matters, which are supposed to break up and form new combinations, passing away partly as gas. This process produces what is known as sour silage, in contradistinction to the kind which is termed sweet. Cattle soon learn to eat either variety with avidity.

We will not take up space to describe the process of ensilage in this place, but simply refer the reader to Bulletin No. 32 of the United States Department of Agriculture, where very complete detail as to the construction and cost of silos, as well as to crops best suited to the process, may be found. We may remark, however, that the most common ensilage crop of ordinary farming in this country is Indian corn. Over a large part of the United States from 15 to 20 tons of clean fodder per acre can be grown without difficulty under the

conditions of ordinary farming. Considering the vigorous growths of Indian corn produced by sewage irrigation, it is probable that experience would soon show that on sewage farms from two to three times this quantity could be produced by growing, say, two crops on the same area in a season.[1]

In England the first experiments with rye-grass silage were made from ten to fifteen years ago, with the result of showing that there was no difficulty in preparing the rye grass for winter feeding in this way. At the present time ensilage is regularly used on nearly all the English sewage farms. Experience with it at the different farms will be given in the detailed accounts of the English sewage farms following.

As to the feeding value of sewage-grown grass, we may refer, for an authoritative exposition, to the reports of the English Sewage of Towns Commission. This commission experimented extensively on this subject and gave its report in great detail. Among other points presented, it shows that very large quantities of milk as well as beef can be produced from cattle fed on sewage-irrigated grass, and that the composition of the milk produced varied but slightly from that produced by cattle fed on ordinary unsewaged fodder. The milk from the sewage-grass-fed cattle was slightly less rich in casein, butter, and sugar than that from those fed on unsewaged grass.

In an experiment with oats, in which 135.5 gross tons of sewage were applied per acre, the gross value of the increased produce amounted to more than 10 cents per ton on the sewage employed; in another experiment, in which 510 gross tons of sewage were applied per acre, the gross value of the increased produce amounted to 3 cents per ton of sewage employed.

In the immediate vicinity of towns, where garden truck can be conveniently disposed of, truck farming will necessarily be an important branch of this special department of irrigation. When, on the other hand, the sewage farms are for any reason situated farther away from towns, dairy farming and the raising of cattle will become the leading branches, the cattle being fed on green forage during the summer and on stored roots, such as mangolds, beets, swedes, etc., and rye grass and corn silage in the winter. Working intelligently on these lines, it is believed that a fine profit can be realized from such farming in almost any locality.

QUANTITY OF SEWAGE TO BE APPLIED.

As to the quantity of sewage which may be applied per acre, the experiments of the Sewage of Towns Commission indicated varying amounts ranging from 400 to 500 gross tons per acre per annum on

[1] For literature of ensilage as applicable to American conditions, see Sewage Disposal in the *United States*, pp. 257–259.

heavy land in wet seasons on ordinary crops to about 9,000 tons per acre on grass plots.

As we have seen, the daily average sewage in this country will probably be at least 80 United States gallons per head, giving the annual amount of sewage per capita at 97 gross tons. On this basis the range of application per acre would vary from the sewage of 5 to that of 93 persons. Include some additional sewage which land may be expected to clarify without reference to the results of cropping, and we may take from 50 to 150 persons per acre per year, though the quality of the soil may be expected to materially influence the result. We may point out, however, that with intermittent filtration areas, provided by the towns for the purpose of purifying sewage when not needed in agriculture, the question of number of inhabitants per acre from which the sewage may be utilized has little significance further than as a guide in estimating the probable quantity of sewage which each farmer may be expected to require in ordinary seasons. For completion of our subject we may give in detail the statistics of the quantity of sewage utilized on a number of the foreign farms, drawing for our information upon the paper, "Notes on European practice in sewage disposal," by Charles S. Swan, M. Am. Soc. C. E., to be found in Volume VII of the Journal of the Associated Engineering Societies.

From the tabulations there given it appears that at the Croydon Beddington farm, with a gravelly soil, the volume of sewage used in broad irrigation may be as great as 3,860 cubic feet per acre per day, which amounts to an average depth of sewage on the area per annum of 32.3 feet. At Doncaster, with sandy or gravelly soils, the average application is 395 cubic feet per acre per day, amounting to a total depth on the area of 3.31 feet per annum. At Leamington, with a soil mostly gravel, the average application is 546 cubic feet per acre per day, amounting to a depth of 4.6 feet on the area.

At the Berlin Malchow farm, with a heavy soil, the average application ranges from 288 to 346 cubic feet per day, amounting to a total depth on the area of from 2.4 to 2.9 feet. On the Berlin Falkenberg farm, with a heavy soil, the average application is 483 cubic feet per acre per day, amounting to an average depth over the area of 4 feet. On the Berlin Osdorf-Grossbeeren farms, with sandy soils, the average application is from 616 to 640 cubic feet per acre per day, amounting to a total depth for the area of from 5.2 to 5.4 feet.

At the Paris Gennevilliers irrigation area, with sand and gravelly soils, the market gardeners apply about 1,305 cubic feet per acre per day, which amounts to 10.9 feet over the area per year. On this point attention is called to the account of irrigation at Gennevilliers on pages 93–98. In filtration without cultivation, as carried on at Gennevilliers, 3,616 cubic feet per acre per day, or a total depth of 30.3 feet per annum over the area, have been applied. The maximum limit at Paris with sandy and gravelly soils was formerly 3,915 cubic feet

per acre per day, which amounts to 32.8 feet depth over the area, but during the last few years even larger quantities have been applied.

THE LIMIT OF TEMPERATURE.

Question is frequently raised as to the temperature limit at which the purification of sewage by either broad irrigation or intermittent filtration can be carried on, and widely varying opinions have been expressed. The last few years, however, have furnished a considerable amount of data on this point, which enable one to form more definite opinions than were possible formerly. If one takes a map of the United States on which the mean winter temperatures at the principal cities are laid down, it will be seen that the curve of 32° mean January temperature (January is taken as being the coldest month) passes between New York and Philadelphia, just south of Columbus and Indianapolis and St. Louis, and just north of Cincinnati. It also passes to the south of Dodge City, Kansas, and to the north of Oklahoma; passes south of Santa Fe, New Mexico, and thence curves north through the State of Nevada and a little to the west of Winnemucca. The curve passes about through the middle of the State of Washington. It may be assumed without discussion that at all points south and west of this line the temperature difficulty will never appear in connection with sewage purification by the land process.[1]

To the north of the line, however, we may define a strip of country the northern limit of which is between Boston and Portland, and to the north of Albany and Oswego, Rochester, Buffalo, Detroit, Grand Haven, Chicago, Keokuk, Dodge City, Denver, and Salt Lake City, within which limits, with proper management, sewage purification by the land process may be carried on in winter without serious difficulty. In the portion of the United States north of this latter limit, probably, special appliances would be needed for a successful winter purification. These conclusions are based upon a study of sewage as received at purification works in winter in comparison with soil temperatures at various depths, as kept at a number of sewage farms, as well as at the agricultural experiment stations in this and other countries.

Our first important fact is that the mean temperature of sewage is much higher than that of the air. At Lawrence, in January, 1888, the mean temperature in the main sewer was 46.5° F. The mean temperature of the air in January was 15.46° F. In 1889 the mean temperature in the main sewer was 45.9° in January, while the mean temperature of the air was 31.40°. Similar differences of temperature as between the sewage and the air are found to exist in other places. This considerable difference between the temperature of the sewage and of the air is sufficient to not only prevent the sewage from

[1] For map illustrating the foregoing in regard to temperature curve, see Allen Hazen, *Filtration of Public Water Supplies*; New York, 1895.

reezing readily, but to keep the ground itself open and free from rost. In regions of large snowfall the sewage passes under the snow, orming a crust of ice on the under side, and the irrigation goes on hrough the unfrozen soil the same as when snow and low temperature re absent. The difference in the degree of purification attained has lready been discussed in the foregoing pages.

As to how the sewage retains sufficient heat to prevent freezing of he ground, we have to consider that water not only parts with its tent heat very slowly, but even after the freezing temperature of 32° '. is reached every pound of water still contains 142 heat units, which ust be entirely withdrawn before a given pound of water can become rozen solid. Another reason why a body of water which is continu-lly receiving accessions of water at considerably higher temperature han the mean of the body will freeze with great slowness may be found n considering that after the formation of an ice cover the loss of heat rom the water is still further retarded by the condition that it can hen take place only by conduction through the ice cover, which has low rate of conductivity, thus leading to still further retardation in he process of loss.

The quality of the material of which filter areas are formed will, owever, influence somewhat the rate of loss of heat in cold weather. ccording to the classical experiments of Schubler on the physical roperties of soil, it appears that the relative power of retaining heat aries greatly in different soils. According to his experiments, lime nd required three hours and thirty means to cool from 145° to 70° '.; clay loam cooled between the same limits in two hours and thirty inutes; heavy clay in two hours and twenty-four minutes; pure ray clay in two hours and nineteen minutes; garden soil in two ours and sixteen minutes; humus in one hour and forty-three min-tes, while water required thirty hours and seven minutes in cooling om 145° to 70° F. The conditions were the same for all of these aterials.

Schubler's experiments also show that black soils retain their heat etter than those which are white and light colored, and that this roperty resides almost wholly in the surface. A practical applica-on of this fact may be made by constructing the broad surface of rtificially prepared filtration areas of dark-colored sands or gravels.

Temperature observations as made at the Berlin sewage farms ow that the mean of the soil temperatures there is considerably bove that of the air. The same fact has been, generally speaking, rought out by an extensive series of soil temperatures taken at the arious agricultural experiment stations in this country, although ere are exceptions, which, however, do not invalidate the general roposition.

Without presenting the full information upon which these deduc-ons are based, we may say that generally at a locality with a mean

air temperature for the coldest winter months not lower than about 20° to 25° F., and with sewage distributed to a purification area at a temperature not lower than about 45° F., purification by the land process may be effected without serious interruption from frost, the winter purification being, as already pointed out, less than that realized in summer. If the mean winter temperature falls for any considerable length of time much below 20° to 25° F., there will probably be trouble from frost. By reason, however, of the facility with which the level embanked areas of the filtration process may be operated as continuous filters during extreme cold weather, it is probable that the filtration process, pure and simple, may be operated at a somewhat lower temperature than the broad irrigation process. As a safe limit, the lowest mean air temperature for filtration may be set at from 18° to 20° F.

The foregoing statements as to practicable mean winter temperatures are to be considered, however, in relation to the quality and temperature of the soil used. Before deciding as to just what can be reasonably expected in a given locality, therefore, one should have at hand a statement of the physical properties of the soil as well as the mean temperatures of the coldest months. As repeatedly pointed out, sandy soils are preferable for both irrigation and intermittent filtration. As regards temperature, this preference arises not only on account of their open texture, but because they possess greater capacity for heat. The great desideratum of successful sewage purification in winter is a medium which will prolong the time of congelation. It is considered that sand answers to this requirement better than any other material.[1]

COST OF LABOR ON SEWAGE FARMS.

When examining a number of the best-managed sewage farms of England in the fall of 1894, the author was much surprised to learn that, generally speaking, somewhat higher wages are paid on sewage farms than on farms of the same character in the immediate neighborhood, and one reason why he is now of the opinion that sewage farming may be made commercially profitable in the United States is derived from the consideration that the wages actually paid for labor on many of the English farms are quite as high or even higher than the present rate of wages for farm labor in many parts of this country.

As regards a comparison, therefore, between the English sewage farms and American conditions, the frequently urged objection that we could not afford the large amount of labor required here certainly has no weight. In order to present this phase of the question in

[1]The reader wishing to go extensively into the relations of temperature to winter purification should consult Chapter XVII of Sewage Disposal in the United States, on "The temperature of the air and of natural soils, and its relation to sewage purification by broad irrigation and *intermittent filtration*," where an extended discussion may be found.

some detail, the author is enabled, through the kindness of Mr. S. S. Platt, Assoc. Mem. Inst. C. E., borough engineer at Rochdale, England, to include the following statements as to the actual prices paid during 1895 at a number of the English sewage farms. This information was gathered by Mr. Platt directly from the managers of the several farms:

At Birmingham, with an area of 1,300 acres, 222 men, 14 women, and 22 children were employed as an average during the year 1895. The men received 21s. per week, the women 10s., and the children 8s. On similar farms worked by ordinary methods in the neighborhood men received, in 1895, 16s. per week, women 9s., and children 6s.

At the Burton-on-Trent farm, with an area of 575 acres, the force employed consists of 4 wagoners, at 20s. each per week; 3 cow men and a shepherd, 19s. per week; 24 ordinary laborers, at 17s. per week, and 7 laborers attending to the sewage distribution, at 23s. per week; 2 foremen, at 30s. per week, one of them being furnished with a horse in addition; 1 weigh clerk, at 20s. per week; 2 men with steam cultivator, 1 at 27s. 6d. per week and 1 at 21s. per week. Four boys are also employed, 1 at 4s. per week, 2 at 7s. per week, and 1 at 9s. per week.

At the Crewe sewage farm, with an area of 269 acres, the average labor consists of 20 men, receiving from 14s. to 21s. each per week. On ordinary farms in the neighborhood of Crewe common labor receives from 14s. to 16s. per week.

At Croydon, with a total area of the two farms of 630 acres, the labor employed is as follows: One man at 32s. per week, 1 at 30s., 1 at 27s., 2 at 26s., 2 at 25s., 12 at 24s., 2 at 23s., 1 at 22s. 6d., 8 at 21s., 5 at 20s., 1 at 19s. 6d., 18 at 18s., 3 at 17s., 4 at 16s., 2 at 15s., 2 at 14s., and 1 at 13s. 6d. The total number of men employed at Croydon is found to be 68, and the average weekly wage is 19s. 10d. per week. On ordinary farms in that vicinity the wages of common laborers range from 18s. to 20s. per week. Carters receive 23s. per week.

At West Derby, with an area of 207 acres farmed, the labor varies from 22 to 40 men, according to the season, the wages paid ranging from 10s. to 24s. per week. On ordinary farms in the vicinity about the same rates are paid. The head foreman receives 30s. per week, together with free use of a cottage, garden, and coal. Six of the regular farm hands are also furnished with cottages and garden free.

At Northampton the total area farmed amounts to 688 acres, the labor including about 50 men, 25 women, and 12 boys. The wages paid are from 15s. to 18s. per week for the men, 10s. for the women, and from 5s. to 10s. for the boys. On ordinary farms in the neighborhood the wages range about 1s. per week less.

At Nottingham the total area farmed amounts to 908 acres, requiring from 40 to 50 men and from 15 to 20 boys. The men receive from 14s. to 17s. per week wages, and are also furnished with good houses

and large garden, rent free. Manure and seed potatoes are also furnished free. The boys receive from 4s. to 10s. each per week. On ordinary farms in the neighborhood men receive 12s. to 15s. per week, without house and garden, and boys about 1s. less per week than on the sewage farm. On the sewage farm all the men employed are paid extra for overtime and are allowed harvest piecework at the same rate per acre as strangers who are not found houses.

At Oxford the total area farmed is 370 acres; the amount of labor fluctuates from 15 to 30 men, according to the season, together with 2 women and 4 boys. The men receive from 12s. to 15s. per week, women 6s. per week, and boys from 3s. to 5s. per week. On ordinary farms in the neighborhood men receive from 11s. to 12s. per week and women 6s. per week.

At Tunbridge Wells, on the north farm, consisting of 191 acres, 1 man is employed flowing sewage at £1 per week and cottage, 5 laborers at 16s. and cottage, 1 laborer at 16s. per week without cottage, and 1 boy at 10s. per week. On the south farm, which consists of 199 acres, 1 man is employed flowing sewage at £1 3s. and 6d. per week and cottage, 4 laborers at 16s. 6d. per week and cottage, 1 laborer at 19s. per week without cottage, 3 at 15s. per week without cottage, and 1 boy at 9s. per week.

At Warwick, with an area of 134 acres, 10 men are employed at 15s. per week and cottage. On ordinary farms in the vicinity the laborers receive from 10s. to 13s. per week.

At Wimbledon, with an area of 70 acres, the labor varies from 3 to 8 or 10 men, depending upon the season. The price of labor ranges from 21s. to 30s. per week, at which prices it is stated that the very best men of the vicinity are obtained. The amount expended in wages on this farm during the year ending March 31, 1896, was £639 3s. 2d.

At Wolverhampton, with an area of 600 acres, the labor amounts to about 22 men and 3 boys, the men receiving from 18s. to 20s. per week, and the boys 6s. Laborers on ordinary farms in the vicinity receive about the same price.

Relative to the cost of management on a number of the leading English sewage farms, we may refer to a return showing the salaries and emoluments of sewage-farm managers, etc., as contributed by Joseph Gordon, Mem. Inst. C. E., borough engineer at Lester, which may be found in Volume XV of the Proceedings of the Association of Municipal and Sanitary Engineers and Surveyors. From this return it appears that at Birmingham the management of the farm is in the hands of a general manager or superintendent, who receives a salary of £350, with use of horse and wagon. At Burton-on-Trent the manager receives a salary of £150 per annum; at Crewe, a salary of £160 per annum. At Croydon the manager of the Beddington farm receives £220, with house and gas provided. The manager of the Croydon Norwood farm receives a salary of £156. At Northampton the manager

eceives a salary of £250, and is furnished in addition thereto with ouse and garden and horse and wagon.

At Nottingham the management is in the hands of the farm bailiff, vho receives a salary of £300 per annum.

At Tunbridge Wells there are two farm bailiffs, who each receive a alary of £120 per annum with house and garden and the produce of a cow.

At Warwick the farm is managed by a superintendent, under the irection of a committee, who is paid £120 per annum.

At Berlin, as stated by Mr. Roechling in his paper on "The sewage arms of Berlin," which may be found in Volume CIX of the Proceedngs of the Institution of Civil Engineers, the labor of the sewage farms s largely performed by misdemeanants; that is, by men sent for various minor offenses to the city house of correction. In 1890 the total number of misdemeanants employed on the Berlin sewage farms amounted to 737, their labor costing the sewage farm about 13 cents each per day. Besides this number of misdemeanants a large number of free laborers were employed on the farms at an average price of about 40 cents per day. By observation it has been concluded that the work performed by two free laborers at this price is fully equivalent to that of seven of the misdemeanants. At this rate it is clear that from a pecuniary point of view there is no saving to the farm management from the employment of the misdemeanants, as, at the rates mentioned, the labor done by misdemeanants at a cost of 91 cents per day is performed by free laborers at a cost of 80 cents per day. There is, however, a decided advantage to the administration of the house of correction, which is also owned and managed, as well as the sewage farm, by the city authorities. As a matter of philanthropy Mr. Roechling says the employment of the misdemeanants may be also highly commended, as it gives the men a chance to acquire regular habits while undergoing their punishment.

In considering the significance of the price of labor paid in England and in Germany in its application to American conditions, it must be remembered that in England the price of the ordinary crop sent to market from the sewage farms will compare with the prices prevailing in the United States very much in the same way and in the same ratio as that which obtains between the price of labor in the two countries. In Germany, on the contrary, where labor is considerably ower, the prices of produce are also lower, all of which must be taken nto account in drawing conclusions as to the possibilities of establishng sewage farms here. In France the price of labor does not vary reatly from the price in Germany.

SANITARY CONDITION OF SEWAGE FARMS.

There has been much discussion at various times as to the sanitary ondition of sewage farms, and formerly much apprehension was xpressed as to the possibility of contaminating not only the well

waters of the surrounding areas, but also the atmosphere in the vicinity. As to the contamination of well waters, the development of a clear understanding of the actual facts in regard to nitrification has gone a long way toward relegating this particular objection to sewage farming to the region of exploded objections, which, as we have seen, is now occupied by a large array of the arguments of the opposition as advanced from twenty to twenty-five years ago. At the Berlin sewage farm the effluent is so pure that it can be admitted into any water course, and can not be distinguished by the senses from the clearest spring water.

In order to obtain information as to the extent to which sewage farming may affect the health of the inhabitants of the farms, the Berlin authorities have established a system of registration of all cases of sickness and death. The following facts bearing upon the sanitary condition of the farm are derived from Mr. Roechling's paper already referred to. The average annual population to which the figures apply was, during the five years from 1885 to 1889, 1,580, of which 986 were men, 285 were women, and 327 were children under 15 years of age. The 958 adult male population included 850 misdemeanants, who were probably impoverished in health by irregular habits of life. The records show that the death rate per 1,000 from all causes was 11.24 in 1885, 9.22 in 1886, 14.83 in 1887, 6.79 in 1888, and only 4.81 in 1889. Of the total deaths, 16 per cent were men, 9 per cent women, and 75 per cent children, the mean rate of the whole five-year period being 9.75. The death rate from the seven principal zymotic diseases, smallpox, scarlet fever, diphtheria, typhoid fever, measles, whooping cough, and diarrhea, was 4.32 in 1885, 3.69 in 1886, 4.15 in 1887, 1.13 in 1888, and nothing in 1889, the mean rate during the period from these causes being 2.53. The period covered by these statistics is, of course, too short for definite conclusions to be drawn, although it may be stated that the same low rates have continued until the present time. If, however, statistics mean anything, they indicate clearly that the conditions of this farm are not in any degree unhealthful. It may also be stated that drinking water for use on the farms is obtained by wells sunk at the points where water is required. With one exception there has been thus far no indication of any trouble with these wells. The reports also show that the sewage farms do not exert any detrimental effect upon the health of cattle kept upon them or on the adjoining farms. At Berlin it is even said that the small sickness which has occurred among the cattle has been imported.

The question of the sanitary conditions of sewage farms was examined at length by a committee appointed by the Royal Agricultural Society in the sewage-farm competition of 1879, to which we have referred. This committee concluded that sewage farming is not in any degree detrimental to life or health. Statistics presented by it show that the rate of mortality, on an average, for the number of years

that the farms considered had been in operation does not exceed 3 per cent per annum, the result comparing favorably with that obtained somewhat more recently at Berlin.

We are obliged to conclude, therefore, that properly managed sewage farms are not detrimental to health.[1]

NUMBER OF BACTERIA IN SEWAGE-FARM EFFLUENTS.

By way of showing the degree of bacterial purification effected by sewage farms we may refer to the following observations made by Prof. E. Ray Lankester on the sewage and effluent of the Oxford sewage farm, England, and the water of the Oxford River, into which the effluent from this farm discharges. These observations were made on the given dates in the summer of 1892.[2]

Comparison of number of bacteria in sewage and in river near Oxford, England.

Sample from—	Bacteria per cubic centimeter.					
	June 27.	July 21.	July 28.	July 29.	September 11.	October 5.
Sewage	648,000	12,000,000	1,688,000	1,688,000	528,000	2,486,000
Effluent	42,000	20,500	60,000	60,500	27,000	27,000
River above effluent	1,020	4,700	14,300	24,300	1,800	2,000
River below effluent	900	11,000	24,900	24,900	9,072	14,580

Professor Lankester states that the most important fact brought out by these studies was that the species of bacteria which belong characteristically to sewage (*B. coli communis*, etc.) were not found in the sewage, but only fluviatile species. He further states that it may be asserted in a general way that the effluent contains no more bacteria, nor other kinds of bacteria, than are to be found in other streams draining from agricultural lands in the neighborhood.

SEWAGE FARMING IN ENGLAND.

Having taken a rapid review of the general subject of sewage irrigation, it is now in order to briefly describe a few of the more notable examples of sewage farming abroad and in this country. First may be considered the English farms, and then, briefly, those of Germany and France. Five examples are given from England typical of prevailing conditions, these being the Croydon Beddington farm and the Leamington, Birmingham, Wimbledon, and Doncaster farms. There

[1] See paper by Dr. Alfred Carpenter, of Croydon, read before the British Medical Association in 1886. Dr. Carpenter lived for many years in the immediate vicinity of the Croydon Beddington farm.

[2] Statement by Prof. E. Ray Lankester to the Royal Commission on Metropolitan Water Supply, Appendix C, 61.

are probably more sewage-purification works in England than in any other country, but they all present merely variations in details.

In regard to the present views of English engineers, sanitarians, and sewage-farm managers, it may be stated that the consensus of opinion, as it appeared to the author in 1894, was decidedly in favor of the land purification process. If for any reason it is necessary that the effluent from sewage-purification works should pass into a stream which is the source of a water supply, the further consensus of opinion appeared to be that it should, before receiving the land treatment, be clarified to the extent of removing all of the suspended and a small portion of the dissolved matter by some of the more inexpensive chemical processes. The same views, it is believed, are now held in the United States by many competent engineers, although the effluents from high-grade intermittent filtration areas are also unobjectionable.

CROYDON–BEDDINGTON FARM.

Croydon Borough is a suburb of London, with a stated total population of about 115,000 to 120,000, the daily flow of sewage amounting to an average of 4,500,000 gallons. In addition to the Beddington irrigation farm the borough has another farm at Norwood. The area at Norwood is stated at 105 acres and that at Beddington 525 acres, making a total area of 630 acres, of which about 525 acres are actually under cultivation. Inasmuch as the Beddington farm is the more interesting of the two, we will confine our description entirely to it. At Beddington 425 acres are in irrigation, the balance of 100 acres being occupied by the farm buildings, cottages, roads, and the ground too high to be reached by the sewage, which is delivered upon the farm by gravity. The buildings upon the Beddington farm include 4 farmhouses, superintendent's residence, and 14 cottages. This farm was designed and laid out by the eminent English sanitary engineer, Baldwin Latham. When irrigation first began, in 1860, the original area was much less than at present, additions having been made from time to time to accommodate the growth of the town and consequent increased flow of sewage.

A considerable portion of the soil is an open, porous, black loam from 6 to 10 inches in depth, with occasional areas of a light, free, open soil, but all suitable for irrigation. The subsoil is gravel and sand. The farm has a gentle slope from east to west averaging from 1 in 150 to 1 in 250. The River Wandle flows to the south and west of the farm. The first underdrains were laid under a portion of the farm about fifteen years ago. They have been laid wide apart, and in some cases as much as 9 feet in depth; conductors vary from 4 inches to 2 feet. The chief value of these drains is that they help to dry the land out quickly after the sewage is taken off.

The slope of the soil of this farm is so uniform that about the only

preparation required was a slight adjustment of the surface by raising at some places and lowering at others, but so little of this as not to cut through the top soil. The main carriers along the higher portions of the farm are usually of concrete about 3 feet wide, and level or nearly level where the ground permits. The secondary carriers are also in some cases of concrete. The small distributaries are made with a plow, a furrow being laid from the secondary carriers down the line of greatest descent and at a distance from each other of from 40 to 50 feet, in order to flow the sewage over all portions of the area to be irrigated. Heavy galvanized-iron or wooden stoppers are used at varying distances down these trenches. For this work, when the field is undergoing irrigation, a man passes over and places the stops at each

FIG. 17.—Outdoor ensilage of rye grass at Beddington.

point as needed. On the lower side of each field there is a collecting ditch, into which the effluent water passes. The arrangement of the farm is such that the effluent of the first irrigation is passed over the fields a second time, and, when necessary, a third time. In this way very efficient purification is attained. The time occupied in passing through three irrigations is stated at from three to four hours. As to the loss of water from irrigation, the general statement is made that about 2 out of every 3 gallons of sewage passed onto the farm flow off as purified effluent, the third gallon having been either evaporated or absorbed by the land or growing crop.

The principal crops raised are Italian rye grass, pasture, mangolds, and other root crops, osiers, cereals, and cabbage. Rye grass, the principal crop, is stated to exhaust itself on this farm in about three

years, when it is followed by a crop of mangolds, cabbages, or wheat and oats, with a return after that to rye grass. Five or six cuttings of rye grass are grown in a season. Mangolds yield especially well here. Wheat and oats are grown chiefly for the straw. Enough horses are kept for working the farm. About 200 milch cows are also kept for the purpose of consuming the large quantities of rye grass and roots grown.

As to the purification effected at Croydon, no analyses appear to have been made in recent years. From a series made after the farm had been in operation for about ten years it is concluded that the purification attained then was very efficient.

This farm was visited by the author on October 20, 1894. At that time of year the main crops had been removed, although fine fields of cabbage and mangolds were still standing, and a casual glance at them indicated the successful results in sewage utilization obtained at this farm. The last cutting of rye grass of the season was in progress at that date, and in one field an outdoor rye grass ensilage stack was in process of making, as illustrated by the photograph, fig. 17. Several pasture and cut rye-grass fields were under irrigation, the sewage coming onto the same black and filthy, and absolutely without any preliminary straining or purification. The first irrigation showed marked improvement; the second showed still more improvement, and, finally, after the third, the effluent flowing in the ditches appeared as bright and sparkling as any stream of water flowing from agricultural lands. The floating matters of the sewage are stated to have never given any trouble on this farm.

Mr. Greenwood, the farm superintendent, stated that 100 acres additional had just been purchased, and it was contemplated to purchase about 50 acres more in the spring, making the total area of the farm when this is done about 675 acres. During the year 1893 the farm is stated to have paid £3,000 more than all cost of operation, not including, however, interest on first cost.

As to the cost of laying out this farm, it may be remarked that by reason of the use of concrete carriers and distributaries the first cost was higher than would now be considered necessary. At the present time the laying out of the farm could be accomplished for somewhat less than the actual cost when done thirty-seven or thirty-eight years ago.[1]

There are a number of country houses along the highways leading through or at the sides of this farm. The author was accompanied on his visit by Lieut. Col. Alfred S. Jones, V. C., a well-known English sanitary engineer, whose residence is on the banks of the River

[1] This is not intended as in any degree a criticism on the work of Mr. Latham. In 1858–1860, when this farm was laid out, we had much less knowledge derived from experience in sewage irrigation than at present. Probably the leading idea was to make permanent work, and from this point of view the work must be considered very successful. Since 1860 we have learned that sewage *can be distributed* in ordinary earth channels equally well, thus not only materially decreasing *the first cost*, but rendering it easier to realize a profit on sewage-farm investments as well.

andle, near the point where the effluent from the Beddington farm ters that stream. In the course of a walk about the farm, a stop as made at the residence of a gentleman whose garden plat of 3 or acres is surrounded on three sides by the irrigation fields of this rm. As to the question of nuisance, the owner stated that no nuiance had ever been created by the sewage irrigation that he had conlered in any degree objectionable, although there were occasionally ght smells in warm weather. When the place was first occupied him, over twenty years ago, he had rented, but on the expiration the lease he had bought the freehold of the property, because it ited him, and he had not considered in making such purchase that value of the property was in any degree injured by the presence the sewage farm. He also said that a neighboring cow yard, where onsiderable number of cows were kept for the purpose, as already ted, of feeding sewage-grown produce, was regularly a source of ich more serious effluvium nuisance to the neighborhood than ever ne from the farm itself. At the time of the author's visit, in Octo-r, absolutely no smell of any sort could be detected in any part of irrigated fields.

The statement was made that no difficulty with the irrigation had er been found here in the severest cold weather. Ice forms on the rface, but the sewage flows underneath it, sinking away into the ound, and the purification still going on, although probably a larger ea is required in winter for a given purification than in warm eather. As one of the model English sewage farms, the Croydon ddington farm has been frequently described.[1]

LEAMINGTON FARM.

In the Royal Agricultural Society's sewage farm competition, to ich reference has already been made, one of the prizes awarded as to the sewage farm at Leamington Springs, which is owned by rd Warwick. This farm was visited by the author on October 25, 94.

The borough of Leamington Springs has a stated population of 27,000, though there is considerable variation in the population, owing to e large number of visitors during the season. The sewage is delivred by the borough upon a farm of about 400 acres, owned by the arl of Warwick, at a distance from the borough of about 2 miles. he borough receives £300 per year for the sewage, and its responsility ceases when the sewage is delivered at the point agreed upon the farm, which is at an elevation of about 131 feet above the mping station. In the agreement it is stipulated that the effluent om the farm shall be purified to the satisfaction of the conservancy mmission of the River Leam, into which it finally flows.

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[1] See Crimp's Sewage Disposal and Rawlinson and Read's Report on Sewage Disposal as made to the Local Government Board in 1876. An extended series of analyses of the sewage and effluent not only *of this farm but of* the Croydon Norwood farm may be found in this report.

The present flow of sewage in wet, rainy weather is about 800,000 gallons per day. In dry weather it is somewhat less. The sewage is to be pumped only between sunrise and sunset, except that in the winter months pumping may begin one-half hour before sunrise and continue to one and one-half hours after sunset. In order to take care of the flow of sewage during the night a storage tank is provided at the pumping station of about 1,250,000 gallons capacity, or enough to hold more than one day's flow, which receives the night flow and also provides for contingencies.

The farm is under the charge of Mr. Castle, as farm bailiff, who stated that the farm operations had been in every sense commercially successful. As a matter of business caution he declined to state just what profits had been obtained, but intimated that in no year were

FIG. 18.—Field of cabbage at Leamington.

they less than 8 per cent. The crops raised are rye grass, roots, cabbages, wheat, oats, and barley. The grains are sown in rotation after roots and cabbages, and are not themselves irrigated at all, the heavy irrigation of the preceding crop of roots being relied upon to support the grain crops. About 150 head of cattle, mostly thoroughbred shorthorns, are kept upon the place, and a large amount of milk is sold, this being considered of superior quality. There are also about 10 acres of fruits which are irrigated lightly. The topsoil of the farm is black and porous, with a gravelly subsoil at from 12 to 15 inches below the surface.

One of the most interesting points learned on this farm was in *regard to the* process of ensilage. Mr. Castle stated that they had for

eral years made rye-grass ensilage both in silos and in stacks in field and had been entirely successful in both ways. The most of silage is made sweet or without salt, but in order to make sweet ge with the best results it is necessary that the silo be filled very kly, or if stacked that the stack be completed and weighted in one day, before any heating begins. The statement was also e that during 1893 a cubic foot was cut out of one of the silos and d to weigh 57 pounds, at which rate a cubic yard would weigh pounds.

wage is delivered to the different parts of the farms in a few lines ain carriers of vitrified tile, which deliver it at convenient points wells provided with gates, from which it flows out into distrib-

FIG. 19.—Stacks of sewage-farm wheat at Leamington.

g carriers and from there into the secondary distributaries laid he contours, and is thence flowed over the land by spade gates r the usual manner. The standing crops of roots and cabbages e very fine and spoke well for the thoroughness of the cultivation, vell as the efficiency of sewage irrigation as practiced on this farm. effluent before leaving the farm is passed over a field of osiers, ence it flows into the River Leam bright and sparkling.

he following details in regard to the cropping at Leamington have n obtained from the report of the Royal Agricultural Society's mittee, made in 1879:

ye grass is grown both for sale and for home consumption. It is allowed to stand longer than two years, and about 25 acres are sown h year, usually in the autumn, at the rate of 3 bushels of seed per

acre. A crop sown in September, 1877, was cut eight times in 1878 and six times in 1879, and then plowed up. In 1878 the cutting of rye grass commenced on February 2. In 1879 that sown in 1878 was first cut April 7. The first cutting yielded 4 tons per acre of green grass; the second cutting, June 4, yielded 16 tons of grass per acre; the third cutting, on July 8, 14 tons of grass per acre; the fourth cutting, August 14, 8 tons; the fifth cutting, September 14, 6 tons; the sixth cutting, October 6, 5 tons; and the seventh cutting, in November, 2 tons per acre, giving a total yield of 41 tons of green grass per acre for the year.

Mangolds are also grown largely on this farm. The seed is drilled in rows 26 inches apart and the plants are hoed out to 10 inches distance in the rows. The sewage is not applied until the plants begin to bulb, when they are irrigated. In 1878 this crop received 21 dressings of sewage while under cultivation, or 8,265 tons of sewage per acre, equivalent to an irrigating depth of 81.8 inches of water in addition to the rainfall.

Ordinary cabbages for market are planted on the level in rows 22 inches distance and the plants 17 inches apart in the rows. The cabbages are irrigated during the period of growth. In 1878 one field in this crop received 17 dressings of sewage, amounting to about 6,102 tons, equivalent to an irrigating depth of 60.4 inches in addition to the rainfall. Parsnips are grown on the level, 6 pounds of seed per acre, drilled in rows 14 inches apart and hoed out 6 inches in the row. The crop is not irrigated, but usually succeeds cabbage or second-year rye grass which has been sewaged.

Carrots are drilled in rows on the level at 14 inches distance and are hoed out to from 4 to 6 inches in the rows. Six pounds of seed per acre are sown. The crop is not directly irrigated with sewage, but, like parsnips, succeeds, either directly or after a second year, a crop that has been heavily dressed with sewage.

Potatoes are planted in drills 24 to 26 inches apart and 12 inches from plant to plant in the rows. They usually succeed rye grass which has been cut the full number of cuttings the previous year. Potatoes are not directly sewaged during the period of their growth. Rhubarb is one of the permanent crops at Leamington, as well as elsewhere. It costs about £50 per acre to purchase roots, prepare the ground, and plant out, and the crop is stated to realize about £40 per acre per year. The plants are irrigated with sewage during the period of growth.

A large acreage of wheat is grown on the farm, but as a rule not under the influence of sewage. Generally the wheat follows some crop which has been heavily sewaged. A considerable quantity of oats is raised, and they generally yield well. This crop, like wheat, is not directly irrigated, but usually succeeds rye grass. Barley is also grown, but not with direct sewage irrigation, following, the same as the others, crops which have been heavily irrigated.

Large quantities of beans are grown as part of the miscellaneous roduction, and which are not directly irrigated with sewage. They sually follow some root crop or cabbage.

Turnips and swedes are also grown on this farm. Green crop turips are sown broadcast, about 3 pounds per acre, and are fed off on ie ground to sheep. The swedes are drilled 16 inches apart and oed out to 9 inches in the rows; 2 pounds of seed are drilled per acre. ewage is used for irrigating this crop to a moderate extent. Turnips nd swedes usually follow either wheat, barley, or oats, although ccasionally turnips are cultivated after rye grass.

Seeds, such as clover, trefoil, and alsike, are also grown to some xtent. Clover is occasionally irrigated in dry seasons with moderate ressings of sewage. Generally, however, the seed crops are not irriated.[1]

BIRMINGHAM PRECIPITATION WORKS AND FARM.

The sewage-purification works at Birmingham present some points f difference from those at the two English towns already considered. hus Croydon and Leamington Springs are both residence towns urely, with a sewage consisting of ordinary house drainage without ny manufacturing waste, whereas at Birmingham we have the sewage f a large residential area as well as that of one of the most extensive anufacturing districts in England.

The natural drainage of this district is into the River Tame, a small tream tributary to the Trent. At an early period the passage into hese streams of large quantities of manufacturing refuse forced upon he Birmingham corporation the necessity of considering some form f sewage purification. In 1871 a special sewerage inquiry committee of the Birmingham common council reported at length as to the est means of treating the Birmingham sewage in order to prevent he serious pollution of the River Tame and its numerous small tributaries, which at that time threatened the corporation with damage uits on every hand. This report is specially referred to because of he thoroughness with which the inquiry was made by the committee. t is included in a volume of nearly 250 pages, and gives in succinct orm a résumé of the whole question of sewage purification as it stood t that time. The committee recommended the exclusion of manufacturing wastes from the sewers and the purification of the sewage tself by intermittent filtration through the land. Subsequently the eport of the committee was somewhat modified; the manufacturing vastes were allowed to go into the sewers, and a crude chemical preipitation treatment, to be followed by broad irrigation, was carried ut.

[1] Further details of the Leamington farm may be found in the report of the Royal Agricultural Society's committee already referred to. Extended extracts have been made from this eport because of the statement made by Mr. Castle that there has been no material change in he management of the farm at Leamington since that report was made in 1870.

Following on this line, the corporation applied to the Local Gc ment Board, under the public health act of 1875, for an order tc a number of detached urban and rural sanitary districts into a t district for the purpose of sewage disposal. The total area c drainage district, as now constituted, is 47,275 acres, with a p population in 1894 of from 700,000 to 800,000.

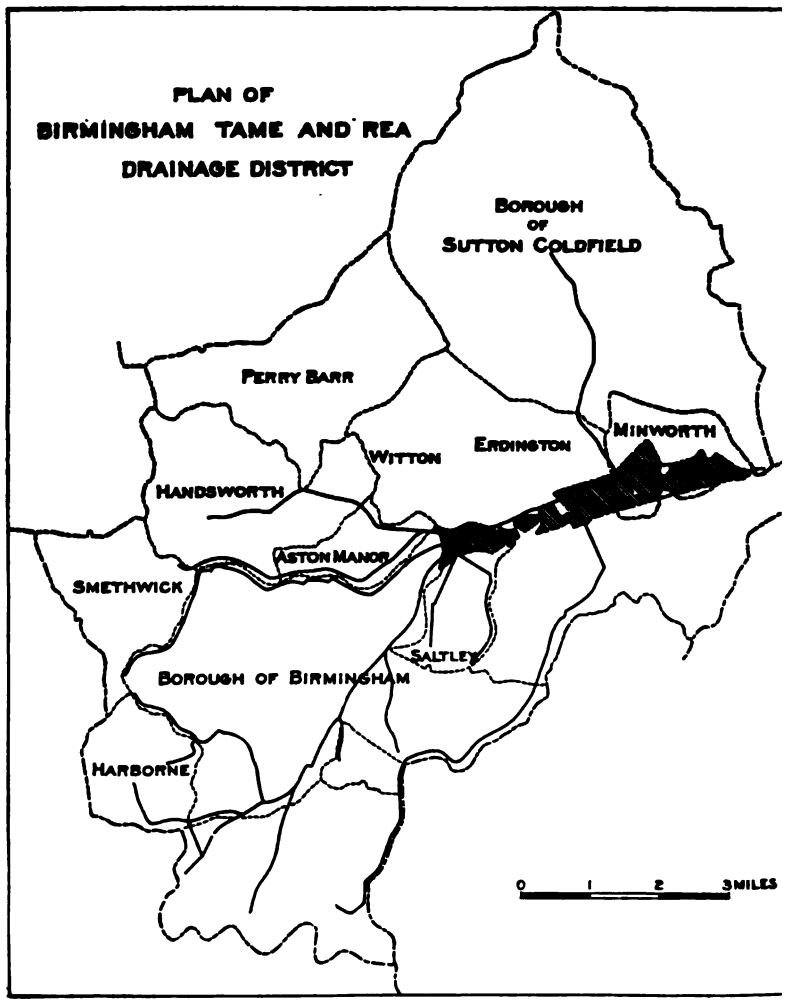

FIG. 20.—Plan of Birmingham Tame and Rea drainage district.

Beginning in 1880, the joint board of the Birmingham Tame anc Drainage District began the purchase of land for a sewage farm have gradually acquired, up to 1894, an area of 1,300 acres avai for sewage disposal. Some of this land has been rented at the of £4 per annum per acre, while the cost of that of which the *hold has* been purchased outright, including timber, buildings

ights, tenants' compensation, etc., has amounted to £152 per acre. As stated by Mr. W. S. Till, city engineer of Birmingham, all this and is very favorable for the purification of sewage, the natural surface being, as a rule, even and unbroken and, with the exception of about 100 acres, of such a level as to admit of irrigating the entire area by gravitation. The subsoil is gravel and sand, varying from 6 to 10 feet in depth. The land is drained to a minimum depth of 4.5 feet, but in many cases, owing to the level nature of the area, a somewhat greater depth has been found necessary at the lower end of the drains. The drains consist of 3-inch and 4-inch agricultural drain pipes placed from about 45 to 65 feet apart and discharging into terra-cotta main drains of 9-inch, 12-inch, 15-inch, and 18-inch diameter, which in turn discharge into the main outfall channels. Roads 12 feet wide, with passing places at intervals, have been laid out in order to meet the various requirements of cultivation, as well as for the conveyance of produce. Farm buildings have been erected in a central position, with entrance lodge, manager's house, and a number of laborers' cottages. Several of the farm buildings and houses existing upon the area have been repaired and extended.

The method of treating the sewage as now carried on is described by Mr. Till substantially as follows: The sewage on arriving near the liming sheds at the upper end of the works is mixed with lime, both to neutralize the acids, which are present to an unusual extent in Birmingham sewage by reason of the large amount of iron manufacturing, and also to assist precipitation, which, however, is stated to be not necessary to so great an extent now as formerly.

The sewage then passes through large roughing tanks, where the coarser impurities are precipitated, whence it passes by the main conduit to the irrigation area, where it is further treated by ordinary irrigation on crops. In order to remove the sludge the precipitating tanks are cut out in regular order and the sludge is elevated by bucket dredges and pumps into movable wooden carriers, in which it flows into beds formed in the land in the vicinity of the precipitation plant. As it comes from the tanks the sludge contains about 90 per cent of water, but after lying on the ground for two weeks much of this water drains away or is evaporated, leaving the sludge in a layer about 10 inches thick and of a consistency which admits of its being dug into land. Crops are then planted on the sludge beds, and after a time the sludge becomes pulverized and capable of receiving irrigation. About 50 acres of land per year are required for sludge, and the same land may, if necessary, receive a coating of sludge once in two or three years. The amount of sewage now regularly treated is about 22,000,000 gallons per day. The controlling board farms the whole of the land itself, no portion being sublet.

The Birmingham sewage farm was visited by the author on October 6, 1894, and some facts were obtained in addition to those stated, which

are derived from a paper on the work of the Birmingham Tame and Rea District Drainage Board, by W. S. Till, C. E., engineer to the board, kindly furnished to the author by Mr. Till at the time of his visit. As one fact of interest, it may be mentioned that the men doing the work of digging the sludge into the land work in gangs and are paid by the cubic yard of sludge actually removed from the tank and dug into the land. Working in this way, they make from 28 to 30 shillings each per week. The cost of labor at Birmingham and vicinity has already been given on page 67.

According to a statement of the assistant farm manager, Mr. Henry Rumble, the land receiving sludge is now allowed to remain fallow until after the following winter, when it is plowed and put into rye grass, to be followed by cabbage, and finally, after about four years, celery is grown upon the land which has received sludge. The celery so grown is of fine quality; that seen growing and in process of gathering was the largest and finest celery the author has ever seen. The statement was also made that the celery from the Birmingham sewage farm brought a slightly higher price than that of the ordinary market gardens of the vicinity, by reason of its superior quality. In addition to rye grass, cabbage, and celery, crops of mangolds, swedes, kohlrabi, green-top turnips, potatoes, and roots of various kinds are raised. Large amounts of milk are sold, as well as beef cattle and swine. At the date of the author's visit a fine herd of 180 swine was observed on the farm.

The sewage farm itself is conducted on lines similar to those followed on farms previously visited, and little need be said in relation thereto. The precipitation tanks work on the continuous principle, and are arranged in the usual manner for cutting out in order to remove the sludge. At present about 1,120 pounds of lime are used per 1,000,000 gallons of sewage treated. Taking 22,000,000 gallons as the mean daily flow, we have then a total daily use of lime of about 24,600 pounds.

WIMBLEDON PURIFICATION WORKS AND FARM.

At Wimbledon we have still another interesting case of sewage purification, which differs in several particulars from those thus far described. This place is a residential suburb of London, situated only about 5 miles southwest of Westminster Abbey. The population is estimated at 26,000. The dry-weather flow of sewage amounts to about 780,000 gallons per day. The average wet-weather flow, which includes a considerable amount of storm water, is stated as about 50 per cent greater. The soil about Wimbledon consists of a heavy clay, on which it is impracticable to purify crude sewage by the ordinary methods of land treatment, especially in a dense residential district where only a limited area in a single body can be found. It became necessary, therefore, to treat the sewage by a crude process

of chemical precipitation or clarification before applying it to land in order to bring the whole treatment within the limits of the available area. The farm consists of 70 acres, of which 67 are irrigated.

The works have been designed with reference to first applying the treatment with lime or other chemicals, to be followed by broad irrigation. Detail as to the chemical part of the treatment may be obtained by reference to Mr. Crimp's Sewage Disposal, from which work, as well as the reports of the Wimbledon local board, the main statements of this paper, aside from those gathered by the author on a visit to the farm in question on October 22, 1894, have been taken.

An interesting feature of the works at Wimbledon is the disposal of the sludge, which is substantially as follows: From the settling tanks

FIG. 21.—Pile of pressed sludge at Wimbledon.

the sludge is swept, when necessary, into a sludge reservoir, whence it gravitates as desired into iron receivers. Lime is then thoroughly mixed with it and air pressure applied to the surface of the sludge, which is thus forced up through an iron pressure pipe into filter presses. The original filter presses employed were made by Johnson, but Mr. Crimp states that two of Goddard, Massey & Warner's now in use, of recent construction, possess improvements in detail over the original presses. As to the labor of sludge pressing, it is stated that the working expense at Wimbledon amounts to about 59 cents per ton of sludge pressed. It should be said that while two men are constantly employed at the work, they could easily press much more sludge if it were there to press. The cost of this item of work

may be expected, therefore, to decrease as the production of sludge increases.

The sludge is pressed into cakes and is stated to be readily sold at the works for about 1s. a ton. Ten tons of sludge as taken from the settling tanks is reduced to 2 tons of cake, 8 tons of water being pressed out. The total quantity of sludge produced in the year 1892 was 5,430 tons, while the total quantity in 1893 was 5,344 tons. It will be seen, therefore, that during those two years the flow of sewage must have been substantially the same. The 6 precipitating tanks in use have a total capacity of 530,000 gallons.

A statement of the annual receipts and expenditures in connection with the sewage farm from 1883 to 1893, inclusive, as derived from the annual reports of the Wimbledon local board, shows that, even with the difficult conditions for successful utilization prevailing at Wimbledon, the sewage farm has paid a small profit every year since it was started, except in 1892, which is said to have been a specially unfavorable year.

The crops grown are rye grass, mangolds, osier, and garden produce. The great decrease in the number of cows kept in and about London has reduced the amount obtained at present for rye grass to a much less figure than formerly. One of the most interesting points to be noted is the great number of good residences located near the farm. According to the statement of Mr. J. Snook, the farm manager, no complaints have been made by the adjacent residents for several years.

The effluent from the precipitation tanks is fairly clear, while the final effluent from the irrigation is bright and sparkling. As stated, the soil is of very heavy clay, which has been underdrained 6 feet deep with lines of drains 60 feet apart. The upper or surface soil has been lightened by mixing ashes with it. Ordinary plowing is to the depth of 1 foot, and once in about three years subsoil plowing to the depth of 2 feet is used. Root crops and cabbages are mostly grown in ridges, between which the irrigation is made.

As originally laid out there were a number of obvious errors in this farm which effectually prevented for several years either a thorough purification of the sewage or a satisfactory utilization of it in agriculture on the heavy clay soil. At the present time the ashes of the town are regularly taken out upon the farm and mixed with the top soil for the purpose of lightening it. Filters of burnt clay have also been constructed for the purpose of receiving storm waters during periods of heavy rainfall. The settling tanks are also provided with valves, by means of which any excess of sewage, due to sudden storms, escapes and is discharged upon these filter beds. These storm-water filters are used on an average from eight to twelve times a year.

The main carriers of this farm are composed of cast-iron pipes, from which the sewage is drawn as desired at different points by means of *ordinary sluice* valves. The secondary carriers leading from the cast-

iron mains are either concrete or stoneware half pipes, laid as shown n fig. 5. The distributaries are laid with a plow and finally finished by spade labor. As a general rule their direction is that of the greatest fall. The distributing channels are cut at a definite distance of 13 feet apart, in order that when cutting the grass the laborer may know the area of the piece he is cutting, as the rye grass when sold standing is disposed of by the square yard.

There is less variety to the crops on this farm than on the others described, because of the large quantity of sewage disposed of per area. Italian rye grass, mangolds, and osiers, the three main crops grown, are those which best stand large quantities of sewage without difficulty.

Experience on the heavy clay lands of this farm indicates that ground to be sown with rye grass should be plowed deeply in the autumn and allowed to remain in the furrow during the winter, in order that the soil may be broken down by the disintegrating action of frost. There is no objection to frequent applications of sewage during this period. As early as practicable in the spring the land should be pulverized by harrowing and the rye grass sown to the amount of not less than from 4 to 5 bushels of selected seed per acre. At Wimbledon the grass grows very rapidly, and with favorable weather the first cutting is sometimes made within eight weeks after sowing. The cuttings immediately succeeding will be heavier than the first, the plant deteriorating rapidly after five or six cuts have been removed. For the best results in the production of forage, rye grass should not be allowed to flower, as a loss of over 50 per cent in weight follows the flowering stage. With favorable conditions and sufficient applications of sewage, as many as eleven cuttings, weighing in the aggregate in the green state about 100 tons, have been obtained in the two seasons following the planting of the seed. After two seasons deep plowing and subsoiling should, if necessary, be resorted to, and the process gone through again. With good cultivation, rye grass may be grown for several years on such heavy soils as those at Wimbledon. The average price obtained for the rye grass at Wimbledon was stated by Mr. Snook to be about £15 to £20 per acre per annum. In some years more than this may be obtained.

In regard to osiers, it was stated that this has been found one of the most valuable crops raised. The demand has always thus far been good, since large quantities are annually imported for basket making and other purposes from Holland and the north of France. This plant likes moisture, and, so far as known, will grow upon any kind of land except peat bog. The kinds found most suitable at Wimbledon are the new osier and the golden willow. The first named is dark skinned and very suitable for basket making. The golden willow is smaller and of finer growth than the osier.

In setting an osier field, sets or cuttings are selected from growing

willows, which are cut in lengths of about 16 inches and planted about 1 foot apart in one direction and about 1½ feet in the other. The cuttings should be planted with their ends nearly level with the ground in order to insure straight shoots. They come into full bearing in the third year, although a fair crop may be got the first year. The maximum growth is attained in about ten years, after which the plant slowly declines, and in the course of fifteen to twenty years it will require reseeding.

The crop is gathered soon after the fall of the leaves by cutting as close to the main stock as possible. The annual yield per acre is stated at from 6 to 7 tons. The price obtained at Wimbledon is about £12 per acre per annum for the rods. This is for osiers; the golden willow yields less and does not bring so high a price as the osier.

The effluent from the Wimbledon farm flows into the River Wandle. As observed by the author, just above the point of junction with the river it was in every way as bright and sparkling as any stream flowing from agricultural lands.

DONCASTER FARM.

As another interesting example of sewage purification and utilization by broad irrigation, we may briefly refer to the farm at Doncaster, which, however, was not visited by the author, but of which it is deemed well to give an account, because Doncaster, while not receiving a prize in the Royal Agricultural Society's sewage farm competition of 1879, was still strongly commended by the committee in their report as an admirable example of thrifty management and an excellent illustration of how sewage can be applied in general farming.

The population of Doncaster is stated at about 30,000 at the present time, with a dry-weather flow of sewage of 700,000 gallons per day. The main drainage works of the town were carried out in 1870, but soon thereafter an injunction was obtained against the Doncaster corporation restraining them from discharging sewage into the River Don. In consequence of this injunction sewage-disposal works were established in 1873. The area available for sewage disposal is about 278 acres, with a very undulating surface. The soil varies between the limits of light sand and stiff red stratified clay. There is also an area of about 20 acres of pasture land laid out for sewage irrigation.

The principle of surface preparation followed was, by reason of the undulations, to change the surface as little as possible. According to Mr. Brundell, the designing engineer, no attempt was made to alter the surface, but the flow of sewage was fitted to the surface by the use of main carriers led along the summits and from them by means of contour distributaries the sewage was finally led over the entire area. Figs. 7 to 13 show how the distribution of sewage on such an area may be treated.

The main carriers are of terra-cotta pipe, laid either below the sur-

ace or in embankments, as may be required. This form of carrier as already been referred to, and is illustrated by fig. 5. The pipes re sometimes worked under a small head. The sewage is pumped rom the borough of Doncaster out onto the sewage farm, a 21-inch ast-iron main with a total rise of 22 feet being used for this purpose.

A great variety of crops are produced on this farm. According to he report of the judges in the Royal Agricultural Society's sewage arm competition, they have been successful in raising black currants, ooseberries, wheat, barley, oats, rye, beans, potatoes, turnips and wedes, clover, clover seed, rye grass, meadow grass, and osiers. A onsiderable amount of live stock is also kept upon the farm. In the arly days there was some prejudice against the milk produced, but t is now accepted without hesitation. The effluent is stated to flow nto the River Don in a state of much greater purity than the water f the river itself, which is seriously polluted by the towns above Doncaster.

SEWAGE UTILIZATION IN GERMANY.

The sewage farms of Berlin are the most extensive thus far carried ut. Since they exemplify both in their preparation and management he best scientific sewage farming of the present day, attention will be onfined to a consideration of them, although descriptions might well e given of the large farms at Dantzic, Breslau, and other points.

BERLIN SEWAGE FARMS.

The information concerning these farms was obtained by inspection y the writer in November, 1894, and from a paper on the sewage arms of Berlin by Mr. Roechling, to be found in Volume CIX of the roceedings of the Institution of Civil Engineers. The detailed statisical statements, as published annually by the Berlin authorities, for he years from April, 1891, to March, 1893, are also at hand. Inasmuch s Mr. Roechling's paper covers nearly every phase of sewage farmng at Berlin, it has been used in some sort as a syllabus in preparing his short account.

At the date of the last census, in December, 1890, the population f Berlin was 1,578,794, the area on which this population is located mounting to about 24½ square miles. The area, not only of the city f Berlin, but of the surrounding country, is generally level. The nly stream of any size is the River Spree, flowing through the middle f the city, which, however, is far too small to admit of the discharge f the sewage of a city of the size of Berlin without treatment.

The sewerage system, as designed by Mr. Hobrecht, the city engineer, is what is known as the radial system, wherein the entire area as been divided into twelve separate districts, which, so far as the ollection of the sewage is concerned, are independent of one another. Each district has a pumping station, from which the sewage is raised

direct to the sewage farms, although in some cases two drainage districts are united to one main. This peculiarity of the Berlin system has determined largely the location of the farms at several different points about the city.

The River Spree flows from west to east through the city. From the systems north of the river the sewage is sent northward, and from the south of the Spree, south; so that, with the exception of a single 12-inch pipe, no sewer or pumping main has been carried under the river. The southern farms are located at a distance from the central part of the city of as much as 12 miles. This makes the disposal of farm produce somewhat difficult. The north and northeast farms are only about one-half the distance of the southern farms from the center of the city, and, consequently, it is stated that the produce there-

FIG. 22.—General view of the North Berlin sewage farms, the village of Malchow in the distance.

from is far more readily disposed of than that of the farms to the south. This statement is made by the Berlin authorities as a reason why the northern farms show better financial returns than the southern.

The general character of the area included in the Berlin sewage farms is well shown by fig. 22, from a photograph. The most of it is practically level, although there are frequently small eminences attaining a height of from 10 to 15 feet above the general level. The soil is generally light and sandy, although in the northern farms there are considerable patches of clay. The subsoil is coarse, open material for nearly the whole area. Taken as a whole, the soil is well adapted for sewage irrigation.

The total area of the Berlin sewage farms as they existed in 1894 is stated at about 20,000 acres, although only a little over half of this was under irrigation at that time. This great property is not only all owned by the municipality, but is mostly farmed by it as well. During the last few years, however, there has been considerable demand for land by market gardeners, who rent the land and take sewage only when they desire it, whence it has resulted that the area farmed by the city itself has been somewhat lessened. The leased land is first prepared for irrigation by the city and then rented out as required. The annual rental for this prepared land is about $21 per acre, while ordinary land in the vicinity brings only about $8.50 per acre, the difference of $12.50 per acre being due to the increased value of land with sewage irrigation. There has also been a demand for rental of

FIG. 23.—An effluent channel on the Berlin sewage farm.

sewage by the farmers who prepare their own land and only take the sewage as required for the best results. In 1894 sewage was applied to about 1,000 acres in this way.

In considering the results of sewage irrigation at Berlin it should be remembered that the water supply has by metering been kept at a very low point, so that the daily use of sewage amounts to only about 14 or 15 gallons per capita. Including the storm water, the daily flow of sewage averages about 25 gallons per capita. The sewage is therefore more concentrated than that of any town thus far considered.

The rising mains from the pumping stations terminate at standpipes erected on the highest points at various parts of the farms. These are open at the top and act as safety valves as well as pressure gauges

for indicating the actual head on the mains at any particular instant, this fact being indicated by a float on the inside of the pipe carrying a flag by day and a lantern by night. On account of the location of the standpipes on the highest points, they form landmarks visible from all parts of the farms. The distributing pipes of cast iron start from the standpipes and radiate in all directions to various parts of the farms, their diameters being reduced gradually at their farther extremities. At various places they are provided with sluice valves and side branches which empty into small tanks dug into the ground. The open earth carriers begin at these tanks. There are sluice gates on the distributing pipes at intermediate points as required.

The laying out of the Berlin farms has been done according to the following scheme: The open effluent ditches, of which an example is shown in fig. 23, follow along the lowest levels of the farm; the bottom width is about 18 inches and the side slope 1½ to 1. The farm has been thoroughly underdrained, mostly with 2-inch pipes laid on the parallel system at distances varying from 16 to 33 feet. The average depth of the feeders is from 3 to 4 feet. The feeders lead into master drains varying in size from 3 to 6 inches, which finally lead into the main effluent ditches just referred to.

In designing the beds the topographical conditions of the ground were very carefully taken into account, and generally sloping ground was utilized for grass plats, to be treated by broad irrigation. The nearly level portions have been made into filtration areas, and the level ground into tanks in which surplus sewage can be filtered by intermittent filtration as required. The irrigation and filtration plats are, so far as possible, rectangular in form, with areas of from 5 to 6 acres. The tanks, however, are larger. They include plats of ground from 5 to 22 acres in extent, surrounded by embankments about 3 feet in height and from 13 to 20 feet wide at the top, in order to furnish space for wagon roads. In summer the tanks are used as filters to dispose of storm waters, and in winter they are used as reservoirs at such times as, owing to long-continued frost, the land is frozen to a depth preventing ordinary irrigation. The Berlin authorities consider the tanks as a necessary adjunct of any sewage farm operated like that at Berlin, although the degree of purification effected by them is apparently not so high as that of the grass plats or the filtration beds. The 5 or 6 acre plats are also subdivided into what are called quarters, in order to enable the irrigation to be properly applied.

Reference has already been made to the earth tanks at the outlets of the main distributaries. The main carriers, which are merely ditches cut in the ground, illustrated by fig. 4, start from these. They vary in depth from 18 inches to 3 feet, and, entering each 5 or 6 acre plat at the highest corner, pass down one side to the lowest *quarter to* be irrigated, and so on to the next plat. Secondary car-

riers, which are also mere earth trenches, are taken off from the main carriers to irrigate such plats as the main carriers do not traverse. From the secondary carriers the sewage is distributed over each plat and quarter thereof by still smaller earth carriers, which are frequently furrows cut with the plow.

The surface of the permanent grass plats has been graded to a uniform slope and the irrigation takes place from the level furrow at the upper end, which, when full, overflows, allowing the sewage to pass in a thin film down the slope. This method of irrigating the grass plats is the one generally followed at Berlin.

The beds have been laid out in terraces, each terrace being made level and separated from the one below by an embankment. The cultivation beds are formed with ridges about 3 feet wide, with the furrows between the ridges 2½ feet wide and 1½ feet deep. Sewage flows into the ditches from one side until nearly full, when it is allowed to stand and filter away through the soil. Turnips, mangolds, cabbages, and other root and vegetable crops are grown on the filter beds.

The foregoing account of the method of laying out pursued at Berlin indicates that both broad irrigation and filtration are used on the Berlin sewage farms, the grass plats representing the broad irrigation and the level beds intermittent filtration with cultivation, while the tanks represent intermittent filtration without any attempt at utilization. As we have seen, this principle is the one now universally adopted in the laying out and management of modern sewage farms. We may conclude, also, from what has preceded, that the principle of leasing sewage to private farmers is developing with considerable rapidity at Berlin, which is in line with the best results in agricultural utilization.

As indicated on page 58, the crops raised at Berlin include a considerable variety of roots, cereals, and ordinary vegetables, as well as oil seeds, which are grown quite extensively. Detailed statements of the yields may be found in either Mr. Roechling's paper in the Proceedings of the Institution of Civil Engineers, already referred to, or in the annual statements published by the city of Berlin of more recent date. These statements show a loss during the early years of these sewage farms, but since the laying out of the farms was completed and more experience has been gained they have shown some small profit.

While the rainfall at Berlin is not large for the whole year, it is heaviest during the growing months, which complicates somewhat the problem of sewage irrigation there.

The best returns have come from the Falkenberg farm, which in 1890 earned about 3¼ per cent on the capital expenditure. This must be considered a very favorable result, especially when it is understood that ordinary land in the vicinity of Berlin does not give an average yield of more than 3 per cent. In comparing the results of

sewage farming at Berlin with ordinary farms it should, however, be borne in mind that the foregoing figures do not include any rent for the land. In case a rental of as much as $5 per acre (20 marks) were to be included, the farms would hardly be more than self-supporting. It is the opinion of the managers of the Berlin farms that with the gradual improvement in the condition of the area under cultivation for a number of years the profits of sewage farming may be expected to increase somewhat. As remarked by Mr. Roechling, the degree of purification attained is the chief test to be applied to a sewage farm; and if wanting in this respect, the farm must be said to be a failure. This point is specially important to bear in mind in considering questions of sewage purification and utilization, because, with the evidence at hand, it is indisputable that with proper management sewage farms may be so operated as to not only utilize sewage at an agricultural gain, but also to give out an effluent of a very high degree of purity. At Berlin the water flowing in the effluent ditches is as clear and sparkling as any flowing from agricultural lands, and the author was informed by one of the head gardeners in the course of walking over the farms that the laboring men who carry their dinners out in the fields were in the habit of frequently taking water from the effluent ditches for drinking, and this, too, in spite of the fact that the use of the water for this purpose had been prohibited by the authorities in charge.

A large number of analyses have been made not only of the Berlin sewage as it comes to the farms, but also of the final effluent. The results are given in such detail as to render any adequate presentation impossible at this place for lack of space. They may be found in Mr. Roechling's paper or in the annual municipal statements. In a general way they indicate that the purification attained is in the highest degree successful.

SEWAGE UTILIZATION IN FRANCE.

Sewage utilization in France, as a whole, has been less generally attempted than in either England or Germany, although the employment of Paris sewage on the Plain of Gennevilliers is, perhaps, on the whole, the most successful case of profitable utilization in agriculture to be found anywhere. The soil of that plain is exceedingly well adapted for the purpose, being light and open, with gravel subsoil of considerable depth. It therefore serves the purpose of a natural filter. Thus far only a small portion of the sewage of the city of Paris has been utilized at Gennevilliers, the remainder being allowed to pass directly into the River Seine. Only a portion of the sewage of Paris is water carried, the balance being disposed of by the pail system, although a recent decree of the French Senate makes it imperative to now construct sewers and connect all houses with the water-*carriage system*.

The utilization of all the sewage of Paris by irrigation has been discussed extensively by the engineers of the city and by Government commissions for many years, with the final result that under a decree of the Senate, bearing date July 10, 1894, the municipality of Paris is authorized to make a loan of 117,500,000 francs for the purpose of extending the sewers to those districts of the city which are now served by the pail system, and also for preparing the necessary areas for land purification at various points in the vicinity of the city.

THE PLAIN OF GENNEVILLIERS.

The history of the irrigation at Gennevilliers is exceedingly interesting. As the result of a considerable discussion, the municipality in 1869 laid down at its own expense the necessary carriers, subcarriers, conduits, and pipes for distributing sewage on land at this place and conceded to the owners and lessees the free use of it until 1880, since which time they have been obliged to pay a price for the use of the sewage. At first there was very great prejudice against not only the use of the sewage as manure, but also against the produce grown by its aid. This gradually died out, and the number of users of sewage has increased from year to year, until in 1891 the total area available at Gennevilliers, which amounts to about 776 hectares, or 1,917 acres, was taken up.

The crops grown under sewage irrigation at Gennevilliers have been successful in the highest degree. They comprise absinth, artichokes, asparagus, beans, beets, cabbages, carrots, celery, kohl-rabi, cucumbers, leeks, melons, onions, parsnips, peppermint, potatoes, pumpkins, spinach, tomatoes, turnips, clover, rye grass, mangolds, wheat, oats, and Indian corn. The market-garden produce yields abundant crops. Indian corn has also an exceedingly good growth here, the stalks attaining a height of from 9 to 10 feet. In order to obtain definite information as to the results to be derived in the agricultural utilization of sewage on the Plain of Gennevilliers, the French minister of agriculture in 1874 appointed a commission to study the question in its economical aspects. The report of this commission shows the following as the yields of vegetables which under favorable conditions may be expected there: Cabbage, as much as 75,000 kilograms to the hectare.[1] Mangolds are stated as yielding 120,000 kilograms per hectare; carrots, 50,000 kilograms per hectare, and beans 15,000 kilograms per hectare. The experience of the last few years is stated to fully confirm the results of the commission of 1874.

Artichokes, which are extensively grown for consumption in France, are stated to yield from 36,000 to 50,000, and even as many as 80,000, heads per hectare. Cauliflowers amount to from 35,000 to 40,000 kilograms per hectare. Garlic yields 37,000 kilograms per

[1] The kilogram is equivalent to 2.2 pounds, and the hectare to 2.47 acres; hence the stated yield of cabbage, in our measures, is 34.14 tons per acre.

hectare; celery, 100,000 kilograms per hectare; onions, 60,000 t 80,000 kilograms per hectare; potatoes, 30,000 to 40,000 kilograms salsify, 10,000 to 12,000 heads, or 25,000 kilograms, to the hectare.

As to the mean value of the number of crops raised, the followin figures are given: Cabbage, from 3,000 to 4,000 francs per hectare cauliflowers, 5,000 to 10,000 francs per hectare; carrots, 3,000 franc artichokes, 5,000 to 6,000 francs; onions, 3,500 francs per hectare, etc (three thousand five hundred francs per hectare amounts to 1,41 francs, or about $281, per acre.) The French reports abound wit statements as to the degree of purification attained at Gennevillier but these are omitted in this place for lack of space. The author vis ited the Plain of Gennevilliers on a rather warm day early in Decem ber, 1894. The effluent was bright and sparkling, and as he wa

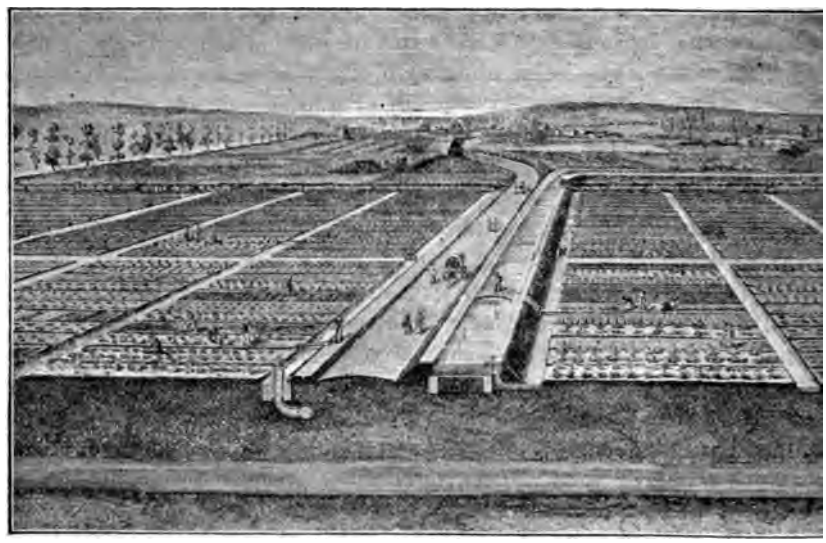

FIG. 24.—Diagrammatic view of the irrigation fields at Gennevilliers.

exceedingly thirsty after a long walk he had no hesitation in dippi up the water of the effluent channel and drinking it, the gentlema accompanying him having made the positive assurance that no har would result therefrom. Thus far there is no reason to believe th the effluent from sewage irrigation from the Plain of Gennevillie may not be used as drinking water regularly with impunity.

The available area at Gennevilliers having been all taken up, th engineers of the city of Paris proposed to extend a main for irrigatio to the edge of the forest of St. Germain, a few miles distant from th municipal usine at Clichy, the point from which the sewage is diverte from the main outlet sewer of Paris to the Plain of Gennevillier Although the sewage irrigation at Gennevilliers had been very su cessful, the project of irrigation in the forest was opposed strongly b *the citizens of the* neighboring communes. Petitions were made an

protests forwarded to the French Senate, the whole forming a large volume of considerable interest as indicating the persistency of the public opposition to the carrying out of great works of public utility of this character. On the part of the city of Paris, however, an equal persistency has been manifested, with the result that the city has finally received authorization to carry out the scheme of purification of Paris sewage, as already detailed in discussing the decree of July 10, 1894.

Among other interesting statistics which have been gathered in regard to sewage purification at Gennevilliers, the French reports indicate that, as in England and at Berlin, the health of people living on and about the sewage farms has not been in any degree impaired. So extensively has the evidence on this point multiplied from the different places where sewage utilization works have been carried out that we may conclude here, as in respect to other details already discussed,

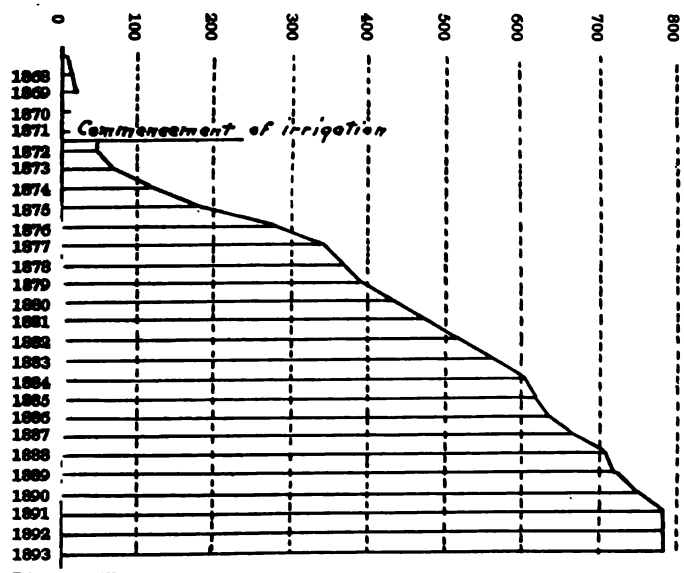

FIG. 25.—Diagram illustrating increase in use of sewage at Gennevilliers. The numbers denote hectares.

that properly conducted sewage utilization is not in any degree prejudicial to the health of either the people engaged in it or those living in the vicinity.

Among other interesting features at Paris, the Model Garden should be mentioned. This includes an area of 6 hectares, on which precise experiments as to the utilization of sewage have been carried on for a number of years under the most scientific conditions possible of attainment, in which have been noted the weight of seed sown, the yield therefrom, the amount of sewage applied, the amount of rainfall, variation in quantity of sewage applied, and many other things tending to afford a definite scientific basis of positive information for the agricultural utilization of sewage.

The results of the experiments at the Model Garden have never been published in full, and the author is indebted to Mr. George Bechmann, chief engineer of the sanitary department of the Seine, for information as to these valuable results. As visited in December, 1894, the Model Garden presented evidence of the many careful and systematic experiments carried out, although at that season of the year little idea could be formed of the relative benefits of sewage to different crops, for the reason that crops were not then growing.

The following particulars as to the irrigation of Gennevilliers are derived from the report of Mr. Bechmann for the year 1893. According to the report, the area under irrigation has remained stationary at 776 hectares since 1891, in which year, as already stated, the entire available area was taken up. Of this area of 776 hectares, 6 hectares belong to the city of Paris and constitute the Model Garden and its dependencies. The remainder is composed of various-sized parcels which are the property of the individual cultivators, who receive sewage only when they desire it. Fig. 25 shows graphically the increase in the use of sewage in Gennevilliers from year to year.

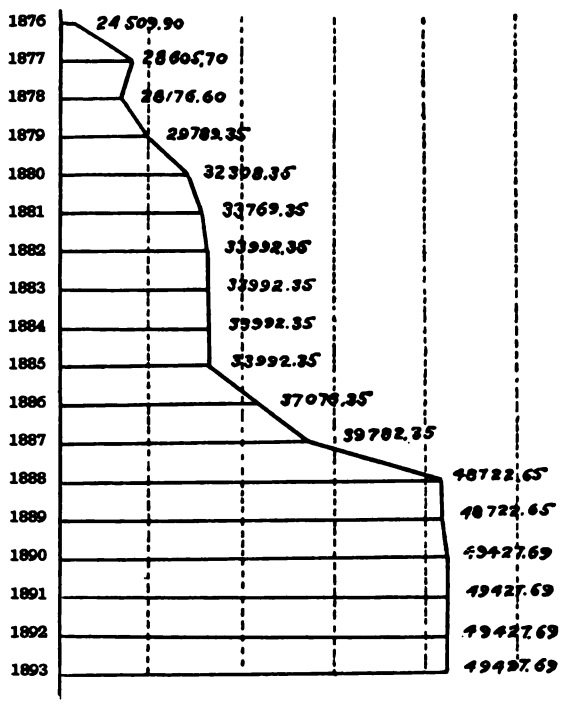

FIG. 26.—Diagram illustrating progressive increase in length of distribution conduits at Gennevilliers. The numbers denote meters.

The sewage is distributed by means of a system of main and secondary channels, with a total length at the present time of 49,427.7 meters. The progressive increase in length of these conduits from the beginning to 1893 is shown by fig. 26. The distribution service is in charge of the agents of the city of Paris, who work according to a system, irrigating successfully the three belts into which the plain has been divided. The force having this work in charge consists of 3 foremen and 23 ordinary workmen, who perform all the labor necessary for a proper and successful distribution of the sewage. Foremen receive 170 francs per month and laborers from 145 to 150 francs *per month.*

otal volume of sewage distributed in 1893 was 33,421,299 eters. Each hectare of the plain, therefore, received on an a little more than 43,000 cubic meters, the distribution per ig, thus, 625,293 feet. The amount actually distributed each shown by fig. 27, while the least area irrigated in one day om month to month as per fig. 28. From this figure we learn minimum area was 49 hectares uary, and the n area 133 hec- r day in Sep-

6 hectares be- to the city of id included in l Garden, 3 hec- l 85 ares were 1 1893 at an an- tal of 600 francs are. The re- of the 6 hec- as devoted to experiments,

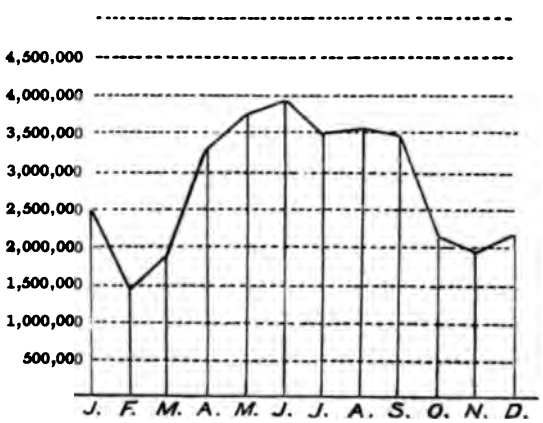

FIG. 27.—Diagram illustrating distribution of sewage by months at Gennevilliers. The numbers denote cubic meters.

lly to intensive irrigation, wherein from 80,000 to 130,000 eters of sewage per hectare per year were applied. Mr. in states that the application of such large quantities of s not prejudicial either to the purification or to the success rops. The experiments at the Model Garden have been directed specially for a few years toward the cultivation of nursery stocks of various sorts, and the results obtained are stated to have been remarkably good.

inimum amount of sewage distributed per nths in 1893. The numbers denote hectares.

The cost of the irrigation at Gennevilliers is said to have been 0.0022 franc per cubic meter of sewage distributed. In ency this would amount to 0.00043 cent per cubic meter.[1] urification attained during the year 1893, as determined by a ! analyses regularly made at the municipal observatory of ris, continues to be absolutely satisfactory. Without refer- he degree of purification attained as indicated by chemical

[1] *The cubic meter* equals 35.94 cubic feet, or 1.33 cubic yards.

analyses, we may merely call attention to the bacterial purificati r According to the Montsouris laboratory determination, the sewage i. it flows in the Clichy main contains 29,454,000 bacteria per cubic centimeter, while the water of the Asnieres effluent drain contains only 5,380 bacteria per cubic centimeter, and that of the Epinay drain 26,500 bacteria per cubic centimeter.

The foregoing is an exceedingly inadequate account of sewage utilization at Paris. The literature of the subject has grown very extensive, and whoever would familiarize himself with all that has been done at Paris must go through this large mass of literature in detail.

SEWAGE PURIFICATION IN THE UNITED STATES.

At the present time there are upward of 60 sewage-disposal plants in operation in the United States and the Dominion of Canada. The limited space here available will not permit an account of these works, but in a subsequent pamphlet of this series it is intended to give a brief description of a few of the more recent or more interesting establishments. Facts concerning many of these may be found in the columns of Engineering News and Engineering Record and in Sewage Disposal in the United States, which latter contains descriptions of and reference to works built in the United States previous to 1893. A complete discussion of existing American works would fill a large volume.

As examples of sewage utilization we may refer to Pullman, Illinois; Los Angeles, California; South Framingham, Massachusetts; Meriden and Bristol, Connecticut; and Plainfield, New Jersey. Intermittent filtration without any attempt at sewage utilization is also practiced at Marlboro, Brockton, and North Brookfield, Massachusetts; Summit, New Jersey; Pawtucket, Rhode Island; and also at a number of other towns. Examples of precipitation plants may be seen at Worcester, Massachusetts, and Canton, Ohio.

Much has been done toward advancing knowledge of sewage purification in this country. At the present time the scientific part of the subject is somewhat in advance of the practical application, and herein lies ground for criticism. The managers of American works have frequently failed to understand the importance of closely following rational theory. It is believed that with good management the American works can be quickly made to show as good results as can be obtained anywhere, for generally they have been well designed—a fact which may be set down to the credit of the engineers.

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

A RECONNOISSANCE IN SOUTHEASTERN WASHINGTON

BY

ISRAEL COOK RUSSELL

WASHINGTON

GOVERNMENT PRINTING OFFICE

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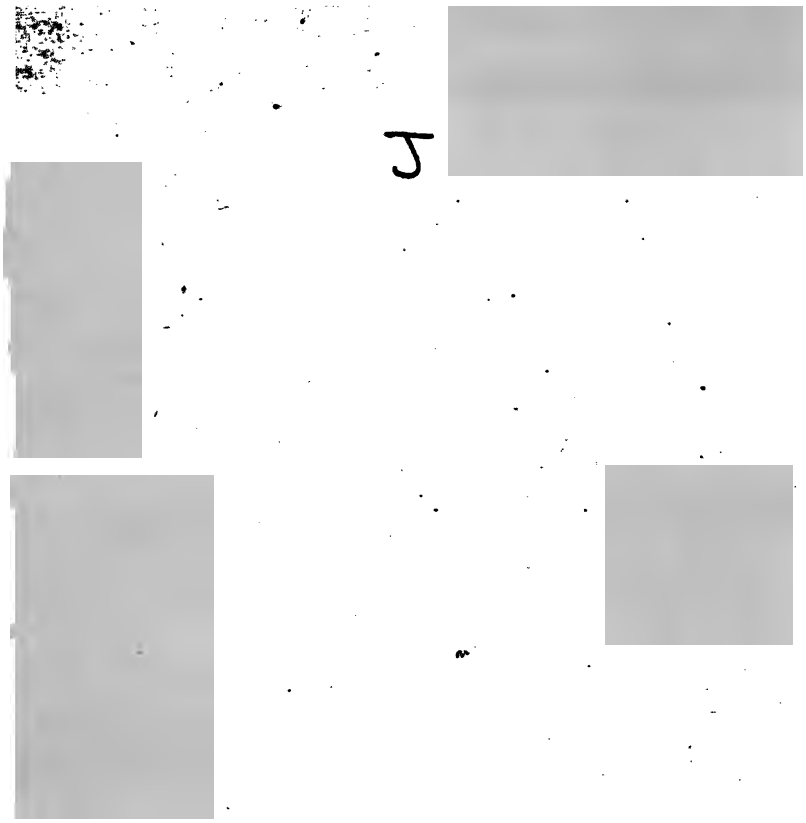

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, February 17, 1897.

R: I have the honor to transmit herewith a paper entitled "A nnoissance in Southeastern Washington," by I. C. Russell, pro- or of geology at the University of Michigan, and to recommend it be published in the series of pamphlets upon water supply and ation. During his long connection with this Survey Professor sell obtained such familiarity with the western part of the United es that it seemed desirable to secure his services in the continua- of the examination of the water resources. He has already lished in Bulletin No. 108 a description of the geologic structure nd adjacent to the drainage basin of Yakima River, Washington, the great plains of the Columbia to the east of this area, giving cial attention to the occurrence of artesian waters. The field k of the last season was to a certain extent a continuation of this mination still farther to the east and south, covering areas in heastern Washington, northeastern Oregon, and adjacent por- s of Idaho. The region, though not arid, depends for its develop- t upon more complete methods of utilizing the water supply, and in turn rests upon a thorough knowledge of the underground cture. The latter, therefore, has been examined and described ome length, as preliminary to a discussion of the employment of water resources.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

on. CHARLES D. WALCOTT,
Director United States Geological Survey.

A RECONNOISSANCE IN SOUTHEASTERN WASHINGTON.

By Israel C. Russell

INTRODUCTION.

Acting under the instructions of Mr. F. H. Newell, hydrographer of the United States Geological Survey, I made an examination of the geology of the southeastern portion of the State of Washington in the summer of 1896 for the purpose of ascertaining how far the nature and position of the rocks of that region favor the hope of obtaining artesian water. The time devoted to field work extended from August 11 to September 21. The region traversed embraces about 5,000 square miles. It will be seen at once, from the time available and the extent of territory examined, that nothing more than a general, or, perhaps more accurately, a preliminary, reconnoissance was aimed at. The conditions, however, are unusually favorable for rapid geological exploration, the region being practically free from forests and the rocks nearly horizontal. For these reasons more confidence, I think, can be placed in the results obtained than at first thought might seem warrantable.

The region examined.—The country chosen for the commencement of my studies is that portion of southeastern Washington which lies south of Snake River. By referring to the accompanying map, it will be seen that a well-defined region, bordered on the south by Oregon, on the east by Idaho, on the north by Snake River, and on the west by the Columbia, may be briefly designated as lying south of Snake River. It is frequently spoken of as the "Walla Walla country," for the reason that Walla Walla is the principal town, or perhaps because the whole of it was formerly included in Wallawalla County.[1] At present this region is divided into four counties, namely, in their order from west to east, Wallawalla, Columbia, Garfield, and Asotin.

[1] Wallawalla County was established in 1854, and originally embraced a much wider territory than is mentioned above, as it extended from the Cascade Mountains eastward to beyond the present eastern boundary of Washington.

The region bounded as described above embraces about 4,000 square miles. In order to learn its geological history, however, it was found desirable to make an excursion southward into Oregon as far as Wallowa, about 30 miles in a straight line south of the Washington-Oregon boundary, and another northward, traveling by rail, through the eastern border of the "Palouse country," as far as Spokane. The hasty reconnoissance northward included a visit to Pullman, Palouse, Garfield, and Spokane. Short excursions were made from each of these towns, and the more general features in the geology of their environs were ascertained. The excursions mentioned were of much assistance in understanding the geology of the region south of Snake River, which is the portion of Washington definitely considered in this report.

Mode of travel.—Southeastern Washington is largely a rich agricultural region. The cultivated lands are inclosed by wire fences, and roads have been laid out through the greater portion of it in a rectangular system governed by section lines. Farmhouses are numerous, except in the more arid western portion and in the Blue Mountains. The geological traveler has to take account of these conditions in planning his journey.

To facilitate my work and to be able to reach all parts of the region to be examined, I chose to "camp out." At Walla Walla I hired two men, Messrs. F. W. De Forest and A. C. Rud, to act as cook and teamster, respectively. We had a two-horse farm wagon, a saddle horse, tents, cooking utensils, etc. To one familiar with the vicissitudes of exploration in unsettled regions, camp life in southeastern Washington offers but few attractions. Nearly every night we camped near a farmhouse, and obtained hay for our horses from the farmer's barns, and in many instances wood for our camp fire from his wood pile. Our camps were of necessity at localities that could be reached with a wagon, but by making side trips with a saddle horse or on foot I was enabled to visit practically all localities that seemed to offer opportunities for gaining information concerning the geology of the country.

The accompanying map (Pl. I), on which the routes followed are shown in a general way, will serve to indicate to some extent how much of this report is based on actual observation and what degree of confidence can be placed in it.

CLIMATE.

The climate of south-central Washington, in the region about Pasco, for example, is decidedly arid. The annual rainfall, judging from weather records in neighboring towns, as Kennewick, Sunnyside, etc., must be less than 5 inches. To the east and west of this arid region a gradual increase in humidity is shown by changes in the character of the vegetation. The nature of the climate on the eastern portion

plateau which occupies nearly all of southeastern Washington
wn to some extent by the following weather records:[1]

Mean precipitation and temperatures for 1895.

Locality.	Precipitation.	Temperature.
	Inches.	°*F.*
Pomeroy	7.37	
Pullman	15.00	
Rosalia	13.69	45.6
Spokane	13.46	48.1
Walla Walla	14.89	53.1

mean annual precipitation at Spokane for a period of fourteen
was 17.94 inches, the summer average being 6.77 and the winter
ge 11.17 inches. At Walla Walla, for a period of eight years,
ean annual precipitation was 16.80 inches, of which 5.96 inches
the summer season and 10.84 inches in winter.

average annual rainfall throughout the eastern portion of
ington, over a belt of country about 50 miles broad and extend-
uthward from Spokane River to the Blue Mountains, may prob-
e taken at 15 to 17 inches. Some years it is considerably less
his, as is shown by the records given above for 1895, and again
exceed this amount, which is assumed as a general average.
vard from this belt a gradual decrease is shown by the character
natural vegetation, and by a decrease and final cessation of
lture.

interesting feature in the precipitation is the manner in which
istributed throughout the year, and the nature of the rain and
all. Precipitation is greatest in December and January, and is
rincipally in the form of snow; July, August, and September are
ularly rainless months. The rain usually falls gently. At no
I have been informed, is it torrential, except at wide intervals,
what are termed "cloudbursts" occur. The fact that precipi-
is normally in the form of gentle showers or snow is of vast
tance to agriculture. The meteoric waters are absorbed and
ed by the fine, deep soils, and do not gather in rills, except
the ground is frozen.

winter, when the land is snow-covered, warm southwest winds,
d "chinook" winds, sometimes blow, and the snow evaporates
sappears rapidly without melting. This is unfavorable to agri-
e, as much moisture is thus lost which would be absorbed by the
the snow were melted slowly. Again, in spring and summer,

[1] Compiled from the First Annual Report of the Bureau of Statistics, Agriculture, and Immi-
[of the State of Washington], by J. H. Price, Olympia, 1896, pp. 22-24.

"hot winds" sometimes wither the grain, and then immense damage is done.

No measures of the rain and snow falling on the Blue Mountains have been made, but the precipitation in that section is known to be much more abundant than on the lower plateau to the north. I have been informed by persons familiar with the Blue Mountains that the snowfall in their higher portions frequently has a depth of 12 to 15 feet. In deep gulches and under the shelter of the forest it remains unmelted until late in the spring. It is this abundant snowfall that insures the permanency of the many creeks which flow from the mountains. Evidently, in a region where there is such a delicate balance between climatic conditions that admit of profitable agriculture and those that are accompanied by a failure of crops, care should be taken to preserve the forests on the mountains, for the reason, if for no other, that they prevent the blowing away of snow, and by sheltering it from the sun delay its melting.

The range in temperature and precipitation of southeastern Washington is shown by the following averages, by counties:[1]

Temperature and precipitation, by counties.

County.	Locality.	General elevation of cultivated portions.	Length of record, in years.	Number of stations.	Temperature.			Precipitation (rain and melted snow; inches and hundredths).		
					Mean annual.	Highest on record.	Lowest on record.	Average annual.	Summer average.	Winter average.
Columbia	Snake River Valley.	1,685	6	1	49.1	109	−15	27.77	9.12	18.65
Franklin	do	.....	2	1	.....	112	−1	9.70	.....	.....
Garfield	do	1,600	4	1	52.1	100	−2	13.93	5.80	8.13
Lincoln	"Big Bend"	1,600	10	1	47.4	105	−31	13.06	.....	.....
Spokane	East	1,900	14	1	47.5	102	−30	17.94	6.77	11.17
Wallawalla	Snake River Valley.	930	10	1	53.1	108	−17	16.80	5.96	10.84
Whitman	"Palouse"	.....	5	3	46.0	98	−19	18.21	6.73	11.48
Douglas	"Big Bend"	2,400	5	2	47.4	104	−30	12.70	.....	.....

VEGETATION.

In the western portion of the area represented on the accompanying map (Pl. I) the vegetation has the desert-like character found so commonly between the Rocky Mountains and Sierra Nevada-Cascade uplifts. Sage brush (Artemisia) growing in scattered clumps gives a monotonous, grayish-green tone to the desolate, treeless landscape. Of brighter green is the common greasewood, which is also familiar to

[1] *First* Annual Report of the Bureau of Statistics, Agriculture, and Immigration [of the State of Washington], by J. H. Price, Olympia, Washington, 1896, p. 22.

every traveler in the more arid portions of the West. Beneath these desert shrubs bunch grasses grow abundantly, unless eaten off by stock, and in early spring the ground is beautified by many lovely blossoms.

As one travels eastward and gradually rises to the summit of the basaltic plateau which forms the greater part of eastern Washington, the desert shrubs disappear and the hillsides and valleys alike are clothed with bunch grasses and are destitute of trees and shrubs. In recent years cattle and horses ranging over these seemingly boundless pastures have eaten off the nutritious herbage and made the land practically a desert.

Before the plateau of southeastern Washington was cultivated, the bunch grasses extended all the way to the mountains of Idaho. The surface of the plateau was then one vast, rolling prairie. The Palouse River, which drains a portion of the plateau, derives its name, it is understood, from the French word "pelouse," meaning greensward, lawn, etc., and is descriptive of the region as it existed for many years after the coming of the white man.

The forests still retain the regions they originally occupied, although inroads have been made with the ax. The Blue Mountains are covered with a varied and beautiful open forest of pines, spruces, and tamaracks, which are valuable for lumber. With these more important trees grow cedars, mountain ash, the haw, and a multitude of wild roses and berry bushes. Similar vegetation clothes the mountains of Idaho and extends down the water courses that enter the plateau region between Spokane and Snake rivers. A few of the buttes in the "Palouse country," which rise like islands through the basalt of the plateau, are also scantily clothed with pines and spruces.

Along some of the streams there are scattered growths of cottonwood, alders, elders, willows, and roses growing in dense thickets. The cottonwood, however, seldom reaches the large size and picturesque development that is seen along the Yellowstone and on the border of many other streams in the Rocky Mountains. The canyon of Snake River, like the valley of the Columbia in its middle course, is treeless. Above Lewiston, however, cottonwood and occasionally a pine appears, and in the canyon of Grande Ronde groves of pine along the river's banks and on islands in midstream, as well as in lateral gorges, give an additional charm to that wild and picturesque region.

Over nearly all of the agricultural portions of southeastern Washington wood of any kind is wanting, and all supplies for buildings, fences, fires, etc., are brought with much labor from the mountains. Wood and water are each highly prized in most of the agricultural regions. Water is frequently carried in tank wagons for a distance of 10 or 15 miles and stored in cisterns for domestic use and the watering

of stock. The conditions that have given large portions of Washington wonderfully rich and easily cultivated soils have been less favorable to man in other directions.

TOPOGRAPHY AND DRAINAGE.

Prevailing topographic features.—The portion of Washington lying to the south of Spokane River, together with what is termed the "Big Bend country"—a region in the central part of the State, bounded on the north and west by Columbia River—is, when minor features are disregarded, a great plateau. This plateau has been moderately disturbed by movements in the earth's crust which have caused elevations at certain localities and depressions at others; the uniformity of the surface has also been broken by stream erosion, and great canyons have been formed. The plateau is lowest in its southwestern portion, where the elevation above the sea, as at Pasco, is but 386 feet, and rises, particularly on its eastern border, to a general level of between 2,000 and 2,500 feet. The general slope in the region between Spokane River and the Blue Mountains is westward. In the absence of accurate topographical surveys, it is impossible to state just what is the slope of the general plateau surface, but from such information as is in hand a broad belt adjacent to the Washington-Idaho boundary appears to be but gently inclined. The chief portion of the descent from the eastern border to the depressed central region near the Columbia is due largely to erosion.

An exception to this general and very gentle westerly inclination of the plateau's surface occurs in the extreme south-central portion of Washington, beginning a mile or two south of Wallula, on the Columbia, and extending far into Oregon. In that region a large block of the originally level plateau has been tilted so as to incline gently southeastward. The Columbia below Wallula has cut a steep-walled canyon some 600 or 800 feet deep through this upraised region. Again, in what may be designated as the southeast corner of Washington, and extending far southward into Oregon, there has been another upheaval which has formed the Blue Mountains. These so-called mountains are essentially a low, flat dome, elevated about 2,000 feet above the general plateau surface. The uplift is so broad in comparison with its height that it is in reality a plateau, although now deeply dissected by stream erosion.

The reader will be greatly assisted as he reads the following pages if he will bear in mind that southeastern Washington, northward from the gentle uplift just mentioned, all the way to Spokane River, is a nearly uniform plateau, the general surface of which is inclined very gently westward. Over much of this vast region, embracing fully 25,000 square miles, and particularly in its eastern half, the country is so nearly level that no one on looking over it could distinguish *any* departure of the general surface from a plain. This

BASALTIC PLATEAU NEAR PULLMAN WASHINGTON.

plateau is, as will be explained later, the surface of a series of horizontal basaltic lava sheets, and will for convenience be spoken of as the "basaltic plateau." On the east this plateau is bordered by the mountains of Idaho. The junction of the plateau with the mountains coincides in a general way, from Snake River northward, with the Washington-Idaho boundary.

The basaltic plateau is crossed from east to west by Snake River, which flows through a deep, steep-walled canyon. There are several streams that rise in the mountains of Idaho and in the Blue Mountains of Washington and Oregon which traverse the plateau in deep, narrow, trench-like valleys, which in fact are true canyons. There are also a few small streams which have their sources on the nearly level plateau and flow through deep valleys, which again are frequently canyon-like. Although the plateau has been deeply cut by the streams flowing across it, yet broad, flat-topped interstream spaces still remain to show what would have been the character of the entire region if it had not been deeply dissected.

Standing on the plateau between the branches of the various streams that have sunk their channels deeply into the rocks, the valleys, canyons, and ravines are concealed from view, and a limitless plain extends away to the horizon in all directions, or to the bordering mountains. In some regions, particularly in the "Palouse country," the surface of the plateau is roughened by short, rounded hills 50 to 80 feet high; but in a general view none of the hills are prominent, and they do not detract from the impression that the surface is essentially level. If one tries to travel in a straight line in any direction across the plateau, one soon learns that it has characteristics which are in marked contrast to its level surface. One may travel through the deeply sunken valleys and canyons for scores of miles, and in the case of Snake River Canyon for over 150 miles continuously, and be shut in at all times by walls of rock that seem like mountain ranges on either hand.

On the plateau's surface solid rock is not in view unless it is in the walls of some neighboring canyon. The soil is fine and deep, and not a pebble is to be seen. In the canyons the somber walls on either side are formed of the edges of thick sheets of basalt, and frequently columnar precipices rise tier above tier, each step being from 50 to 100 feet or more in height. The walls of the smaller canyons are in numerous instances from 500 to 1,000 feet high. The lateral canyons that join Snake River have a depth of 2,000 feet, that being the general depth to which that master stream has dissected the plateau from Lewiston nearly to its junction with the Columbia.

The views beheld on the uplands and in the valleys are thus as strongly contrasted as if they belonged to entirely different regions. As the railroads usually follow the valleys, a traveler is impressed with the prevalence of black basaltic rocks. In crossing the uplands,

the total absence of rock exposures over broad areas frequently leads one to wonder if solid rock actually exists at a moderate depth below the fine soil of the surface.

Where the general plateau rises to make the lower slopes of the Blue Mountains, and throughout that more elevated portion of the plateau, deep erosion has taken place, as well as deep rock disintegration and decay. The foothills of the Blue Mountains are rounded, and have beautifully curving outlines and contours. The first impression one gets on seeing these mountains from the north and west, as from the vicinity of Walla Walla, for example, is that they are composed of soft, easily eroded rocks. The similarity of the hills in slopes and general features to the forms assumed by elevations composed of unconsolidated clay or easily eroded shales, as they waste away beneath the beating of rain and are cut by rivulets and brooks, is so striking that one is astonished when one learns that the Blue Mountains are in reality composed of layer on layer of horizontally bedded basalt, a rock that is among the most resistant to mechanical wear of those commonly found on the earth's surface. As the reader will learn later, the basalt, although hard and resistant to forces tending to abrade it, yet yields with comparative rapidity to agencies which lead to disintegration and decay. The basalt in the region here considered weathers readily, and the loose products of disintegration are not carried away so rapidly as they are formed. A fine, soft, residual soil covers the land and imparts to nearly all its minor features the characteristic flowing outlines and gentle curves so common in regions where soft rocks alone occur. It is only in the canyons, even in the elevated and most completely dissected portion of the plateau forming the Blue Mountains, that the angular forms due to solid rock exposure attract attention.

The prevailing colors in the landscape to be seen on the plateau's surface, when not due to vegetation, are light yellowish-gray in the western part and dark brown—the color of rich humus soil—in the eastern portion. The bright reds and yellows so common in many regions of deep rock decay, especially where the climate is humid, nowhere meet the eye. Not a trace of the deep red so characteristic of the soils of Virginia, and of the southern Appalachian region generally, can be found in all of the deeply decayed surface of the basaltic plateau.

In a far-reaching view during the summer season over the surface of the plateau surrounding the Blue Mountains, except on the east, and also northward through Whitman and Spokane counties to Spokane River, the universal colors are brown and yellow—the brown of plowed land and the golden of wheat fields. The wheat lands as a rule are sown but every other year, so that practically half of the land lies fallow each summer. After the harvest, when the stubble fields are plowed and the soil is moistened with rain, the fields become

ark brown and appear almost black. In the canyons, where one is vershadowed and shut in by walls of basalt, the tone of the landcape is always somber, and frequently oppressive. The black walls f rock find but little contrast in the scant vegetation. The polished nd shining stems of the bunch grass, however, which grows on every jutting ledge and smooth talus slope, frequently clothe the dark precipices with a silken garment of pearly gray.

Throughout the entire region from the Blue Mountains northward to Spokane River, and westward from the mountains of Idaho for 100 miles or more, the general features of the land are the same. The topography is young. The streams have not advanced far in their task of cutting away the rocks forming the plateau and of reducing the land to sea level. This appointed task, although well begun, has been delayed, and over the central and western portions of the plateau has been entirely checked by a decrease in rainfall. It is a relief to leave this region of broad plateau surface and narrow trench-like valleys—not only of young but infantile drainage—and visit the extreme southeastern corner of Washington, where a similar work has been carried on more energetically. The Snake River has there cut through the eastern flank of the Blue Mountain uplift and excavated a canyon about 4,000 feet deep and not less than 15 miles broad from brink to brink. An important tributary river, the Grande Ronde, rising in many branches in the Blue Mountains, has excavated an intricate series of branching canyons, the main trunk of which is as deeply sunken in the rocks as the magnificent gorge of the master river. In this region the topographic features were originally the same as in the less completely dissected portions of the lava-covered country, but for certain reasons the work of the streams is further advanced. The spaces between the streams are no longer flat-topped remnants of the plateau's surface, but the entire region bristles with sharp-crested ridges and is diversified in a wonderful manner with spires and pinnacles.

If a person climbs to the summit of one of the higher ridges and gains an elevation of about 3,000 feet above the canyons on either side, he will see that many other ridges rise to approximately the same heights and that what appears to be a group of sharp, angular mountains, separated by a labyrinth of canyons with silvery threads of water in their bottoms, is in reality a deeply dissected plateau. The topography is still young, although approaching maturity. The streams have not yet widened their valleys materially, but rapid decay has crumbled the walls between. The region treated in this report thus furnishes splendid examples of the various stages in the process by which a plateau is eaten away by streams. If space permitted, it would be instructive to take the reader to the mountains of ancient crystalline rock surrounding the basaltic plateau on the east

and north and point out the characteristics of a region that has lo been exposed to the rain, sunshine, and frost, and from which t streams have been carrying their burdens of disintegrated rock geological ages. We could thus learn what is meant by the term topography. The forms of the original uplifts are lost, and only remnants of once lofty mountains remain.

The bases of the old mountains were partially submerged by t overflow of molten lava that formed the plateau of southeaste Washington. The lava entered the valleys and gave them level flo of rock. Mountain spurs project into the plateau, like headla along the ocean shore. Some of the old mountains, separated erosion from their neighbors, were completely surrounded by the in dations of lava and now rise as islands above its surface. Step Butte is an example of these ancient peaks which project through lava of the plateau. These interesting features in the topography the border land between Washington and Idaho will be better und stood, however, after the character and origin of the basaltic rock that region are discussed.

General characteristics of the drainage.—All of the lines of dra age in the portion of Washington here treated lead to Columbia Riv The principal stream is Snake River, which flows across southeast Washington from east to west in a deep canyon, which is the str est natural boundary in the region. South of Snake River, all of perennial streams rise in the Blue Mountains and flow in all directio their courses being determined by the original slopes of the uplift. I the language of the geographer, these are "consequent" streams. Al of them, as was stated in describing the general topographic feature of the region, traverse deep gorges in the flanks of the Blue Moun tain uplift, and in numerous instances, on gaining the less undisturbe plateau surrounding it, flow through deep canyons. The stream from the Blue Mountains, which are tributary to Snake River, joi that stream in canyons that at their mouths are as deeply cut as the canyon of the main river.

Throughout the basaltic plateau north of Snake River the principa streams rise in the mountains of Idaho, and, with the exception o Spokane River, have their sources near the Washington-Idaho bound ary. In crossing the basaltic plateau, the valleys and canyons of these streams sink deeper and deeper. The minor streams from the mountain are tributary to two rivers—the Palouse, which empties into Snake River, and the Spokane, which joins the Columbia before it makes its wide detour to the westward.

Besides the streams mentioned—which, however, include nearly all the perennial surface water in the portion of the basaltic plateau under consideration—there are minor streams, mere brooks, in fact, which rise in valleys excavated in the plateau when the rainfall was more abundant than at present, and are fed mainly by springs and the

eral seepage from soil and rocks. The channels of many of the ll streams are dry in summer, or their water may flow for a short ance, but fail to reach the main rivers. Some of these trunkless nches are indicated in the accompanying map (Pl. I), but as they sensitive to minor climatic changes they vary materially in length n month to month, and almost from day to day, and can not be irately plotted.

nake River.—As already stated, the principal river of the south- ern portion of Washington is Snake River. With the exception he Columbia, this is the only navigable river in Washington east of Cascade Mountains. It has its source far to the eastward, in the nity of the Yellowstone National Park, and flows through south- Idaho. In what may be termed its middle course, for about 35 es, it forms the boundary between Washington and Idaho, and n bends abruptly westward, where Lewiston is situated, and for 130 es flows in a deep trench in the basaltic plateau to the Columbia. At the southeast corner of Washington the canyon of Snake River fully 4,000 feet deep, but below Asotin the height of its walls creases, and thence to near its mouth it has a nearly uniform depth 2,000 feet. The walls of the canyon are precipitous throughout, and numerous instances are nearly vertical for a large portion of their ight. This great gash in the rocks, of which the 160 miles below unt Wilson is but a portion, has been worn by the river in dense, istant rocks. The canyon walls throughout the region treated in s report are, with slight exceptions, formed entirely of the edges horizontally bedded basalt. The weathering of the edges of the saltic sheets has caused them to recede unequally and form steps terraces in the faces of the precipices. Where the walls are steep- ; they present a series of narrow steps covered with soil and clothed th grasses, separating vertical rises of bare and frequently columnar ck, varying in height in most instances from 50 to 125 feet.

The canyon walls, to an observer from below, frequently appear to nearly vertical, but the impression of their steepness gained from ch a view is usually much exaggerated. Owing to talus slopes on e shelves and the fact that the escarpments of solid rock are fre- ently broken by side gulches, I think it is safe to say that nowhere there a space half a mile in length up which one might not climb. ttle and horses graze on the canyon walls in many places. Expe- nce has made these animals nearly as sure-footed as goats, but eached bones at the base of the precipice show that occasionally cidents happen to them.

The walls of the canyon are scored by steep lateral gulches, with ttress-like ridges standing between. Many tributary streams enter e canyon at the level of the river, and have curved and branching eral canyons and gorges which extend away from the river 10 miles more before gaining the surface of the plateau. The work per- rmed by flowing water in excavating the numerous canyons and

valleys is impressive, and most striking examples of stream erosion meet one on every hand.

Snake River is a swift stream, the descent in the portion below Lewiston, as determined by the United States Engineer Corps, being 2.48 feet per mile, and is still engaged in corrading the bottom of its channel. Rapids due to solid rock occur at numerous localities.[1] Many of these obstructions have been removed for the purpose of facilitating navigation, but at low-water stages danger still exists. Steamboats have ascended the river from its mouth to Wild Goose Rapids, a distance of about 170 miles; but owing to numerous rocks and shoals below Riparia, where a branch of the Union Pacific Railroad now crosses the river, navigation is practically confined to the portion of the river which lies between Riparia and Lewiston. Other navigable reaches of the river occur above Wild Goose Rapids, but they are beyond the region under consideration.

Measurements of the volume of Snake River are not necessary to impress the beholder with the fact that it is an important stream. Its broad, swift current assures one that the waters of a vast region are there journeying to the sea. At the lowest stages the river is in general about 1,000 feet broad. Measurements made by officers of the United States Engineer Corps at Texas Rapids show that 26,000 cubic feet of water flow past during each second. When the snow is melting on the mountains of Idaho and Wyoming the river rises from 20 to 30 feet above its summer stage, and becomes a wild, rushing flood of muddy water. Its volume at such times must be in excess of 100,000 cubic feet per second.

As has been stated, the river is still deepening its channel. But little lateral erosion has taken place, and no general flood plain borders its shores. Where the river forms sharp bends, more particularly in the portion below Lewiston, there are frequently deposits of sand which rise a few feet above ordinary high-water stages. These "bars," as they are termed, are in some instances 200 or 300 acres in area. When planted with fruit trees and properly irrigated these light, sandy lands yield splendid crops of peaches, apricots, plums, grapes, etc. The warm climate of the canyon is especially favorable for fruit raising. Above Lewiston, where the canyon is deeper, and where certain changes occur in the character of the rocks inclosing it, the gorge is wider than where it crosses the basaltic plateau in its westward course, and the terrace-like lands in its bottom are of greater extent, although nowhere more than a few hundred feet broad.

An interesting episode in the history of Snake River Canyon is recorded by fragments of a high gravel terrace that occur in it. At

[1] In connection with the fact that Snake River is still deepening its channel, it is of interest to note that Columbia River is engaged in a similar task. At the head of the steep-walled canyon through which the Columbia flows, below Wallula, ledges of basalt cross the stream, but steamers can generally traverse the deeper channels. This obstruction is due to movements, *apparently still in progress*, in a large block of the basaltic plateau which has been uplifted *across the course of the stream*, and for a time caused it to spread out and form a large lake.

nost any locality on the bank of the canyon an observer will have view, usually on the concave side of a curve in the river course, a rrace of coarse gravel and sand, the surface of which is about 360 et above the stream. The descent from the flat surface of the ter-ce to the river is usually a smooth slope with an inclination of from to 22 degrees. The canyon was at one time filled from side to side ith deposits of the character shown in the terrace and to a depth corded by the level of the deposits remaining. The river has since excavated its canyon, leaving fragments of the former filling at calities from which the current was deflected. The gravel and sand ferred to show that the river, after excavating its canyon to its pres-nt depth, was checked in its rate of flow or so greatly overloaded nat it could not carry away all the débris brought to it, and deposited s excess of load so as to raise its bed 360 feet. Subsequently, re-ewed energy, or a decrease in the supply of débris delivered to the ver by its tributaries, allowed the stream to carry away the greater art of the material deposited.

The gravel deposit referred to extends into each tributary canyon. n such situations the lateral streams have cut modern channels hrough it, leaving terraces as in the main canyon. These gravel eposits are composed in part of worn and rounded fragments of asalt, but consist principally of quartzite, granite, and igneous rocks f older date than the basalt. The nature of this material shows that was brought by Snake River from far up its course. The gravel as carried from the main canyon in some instances for several miles p the tributary canyons, as may be seen especially along Tokanon iver at Starbuck, and checked the flow of the lateral streams. Small kes were formed in some instances in the side canyons, owing to the bundant deposition of material at their mouths.

Terraces similar to the great terrace in Snake River Canyon occur long the upper Columbia on the border of Spokane River, and to a ss marked degree in the canyons and valleys of the streams flowing om the Blue Mountains, showing that the widely extended influence hich caused the streams to deposit a part of their loads affected a ery large portion and probably the whole of the hydrographic basin f Columbia River at a comparatively recent date. The nature of ie change which caused so many streams to partially fill their chan-els and then reexcavate them will be discussed later.

Walla Walla River.—This is one of the few streams having river-ke proportions which rise within the region covered by the Columbia va. Its various branches head in the northern and northwestern ortions of the Blue Mountains and follow westerly courses. Their nited waters, which enter the Columbia at Wallula, form a stream nat in late summer has an average width of 50 to 60 feet, and dis-harges by estimate from 100 to 150 cubic feet per second. During igh-water stages their volume is increased many fold.

In common with all other streams in southeastern Washington, the Walla Walla is clear except after rains, and furnishes wholesome water for domestic use. Where the many branches of the river leave the mountains they are especially clear, for the reason that they are supplied by infiltration, and all matter in suspension has been removed. The Walla Walla and its branches furnish instructive examples of what geographers term "consequent" streams—that is, streams which are directed in their course by the original surface slope of the land. As has been stated, the Blue Mountains are an upraised portion of the basaltic plateau. The uplift has the form, at the north at least, of a low, flat-topped dome, in which the rocks are horizontal except about the gently inclined margins. The general plateau surface to the northward, as already stated, slopes gently westward. The streams from the mountains radiate in all directions, but those which reach the lower plateau change their courses in obedience to the general slope of the surface in which they have sunken their channels. This is seen especially in Touchet River, the principal tributary of the Walla Walla from the north. This stream is formed by the union of several branches which start on the north side of the Blue Mountains and flow northward down the gentle slope of that uplift until the lower plateau is reached and then bend westward. The trunk stream of the Touchet has its direction determined by the westward slope of the plateau it traverses for 20 miles. This slope is not continued to the Columbia, however, but an upheaval of another portion of the tableland lying principally to the west of that river, and briefly described in the next paragraph, changes the direction of the Touchet and causes it to flow southward for about 12 miles before joining the Walla Walla.

Immediately south of Wallula is another block of the Columbia lava, which, as previously stated, has been gently tilted. The tilting is so moderate and affects such a large area that the edges of the lava sheets appear horizontal. The upraised area is bounded on the north by a line of cliffs near the Columbia. When followed eastward, these cliffs lose the precipitous character and change to hill slopes which die away, some at a distance of 20 or 25 miles. This line of abrupt change in slope probably indicates the presence of a break and the upheaval of the rocks on its southern border—that is, the uplift has been by faulting. In looking westward from the Blue Mountains, it is evident that the uplift just described has given a southeasterly slope to the surface of the country, which extends far southward into Oregon.

The Walla Walla River on leaving the Blue Mountains flows westward in a deep canyon, the direction of which was determined by the slope of the uplift. At the foot of the mountain it emerges as a surface stream, and is turned northward by the slope produced by the upheaval south of Wallula. Not only does the branch of the Walla

Walla, for which the name of the trunk stream is retained, behave in the manner described, but several other branches, of which Cottonwood, Russell, and Mill creeks are the most important, also become surface streams on leaving the mountains. These various branches, where they come together in the vicinity of Whitman, about 6 miles west of Walla Walla, are depositing the loads they carry during floods and building up their channels and flood plains. On account of the filling that is in progress, some of the branches, notably Mill Creek, divide, after the manner of a stream on its delta, and contribute their waters to the Walla Walla through two or more mouths. As one continues on down the Walla Walla to its junction with the Columbia, its channel grows gradually deeper and deeper, and below the mouth of the Touchet and near Wallula is certainly 50 or 60 feet below the general surface.

This abnormal behavior of the Walla Walla and its branches has led to legislative enactments which determine what proportion of the waters should be allowed to flow through certain of the bifurcating channels.

The manner in which the streams near Whitman are raising their channels so as to allow their waters to divide is a matter of much geographical interest, as it indicates that movements in the basaltic plateau are still in progress. The depressed region between the Blue Mountains and the smaller uplift to the west is probably slowly sinking. The rate of this subsidence is such that the streams are barely able to keep pace with it by grading up their beds. During high-water stages, I have been informed, expansions of the streams occur which resemble lakes. The expanded waters of the creeks are then united and much of the individuality of the various channels is lost.

The several branches of the Walla Walla furnish excellent sources of supply for town water and for irrigating purposes. In another section of this report the manner in which Mill Creek is utilized at the city of Walla Walla will be described. For purposes of irrigation, in order to make full use of the natural conditions, it will be necessary to store the winter run-off in the canyons of the Blue Mountains and hold it for summer use. If this can be done economically, a very large portion of the rich lands along the Walla Walla and its tributaries can be made many times more productive than they are at present.

Tokanon River.—This so-called river and its principal branch, the Pataha, rise on the north side of the Blue Mountains and enter Snake River through a deep canyon. The Tokanon and Pataha flow northward in their upper courses, their direction having been determined in their infancy by the slope of the surface, but before uniting they curve westward, in obedience to the gentle westward inclination of the plateau into which they have carved their channels. After the Pataha joins the Tokanon the latter flows west for 6 miles and then turns at a right angle on entering a gorge which leads it to Snake River. A

careful survey would probably show that the Tokanon in its youth continued to flow westward and became tributary to the Touchet, but that it was diverted at the present site of Starbuck by a small high-grade stream that flowed to the Snake.

The Tokanon at its mouth is but a brook in summer, across which one may step on the larger stones strewn along its channel without wetting one's feet. The Pataha was dry in its lower course when I visited its valley in August, and had shrunk back as far as Pomeroy. The canyons and valleys through which these two streams flow are deep and out of all proportion to the streams that occupy them. In its lower course the Tokanon is nearly 2,000 feet below the general level of the adjacent plateau. Many other examples of this nature indicate that the streams of the basaltic plateau were formerly larger and more numerous than at present.

Deadman Creek.—The creek with this doleful name, which, however, is suggestive of its own nearly terminated existence, is an exception to most of the streams of the basaltic plateau, for the reason that it does not rise in an elevated region, but is supplied in a feeble manner by the rains falling on a portion of the plateau that is almost completely cut off by deep canyons from all other portions. The deep, canyon-like valley through which it flows has a steep grade and many branches, some of which are now dry. Its catchment basin when the drainage was most vigorous was about 100 square miles in area, and the development of the streams had progressed until its numerous branches furnished a convenient avenue of escape for the waters that fell on every part. The stream in its days of vigor cut down its channel nearly to the present level of Snake River—that is, to a depth of about 2,000 feet—in the solid basalt. At present, as already stated, many of the once tributary valleys are dry and desolate, and the trunk stream is shrunken during the summer season to a mere rill. The soil throughout the valley is deep and rich, but there is no water for irrigation. The hillsides and the remnants of the plateau surface are also fertile, and fortunately absorb sufficient moisture from the light rains and winter snow to admit of their cultivation for wheat.

Alpowa and Asotin creeks.—The drainage from the northeastern slope of the Blue Mountains in Washington is conducted to Snake River through two channels, known as Alpowa and Asotin creeks. Each of these creeks rises in many branches on the slopes of the mountains, and all at first are surface streams, but on account of the cutting down of Snake River Canyon, into which they discharge, they have sunk deeply into the plateau and near their mouths have lowered their channels as rapidly as the master river. The Alpowa is little more than a brook in summer, but its waters serve to irrigate some 300 acres of orchard lands near where it joins the Snake. The Asotin is large and brings a never-failing supply of pure water to the

ttle town of Asotin. A costly irrigating canal is now being built r the purpose of conducting its water to a broad area of bottom land Snake River Valley opposite Lewiston. Some account of this bold ndertaking will be given on another page.

Grande Ronde River.—On the east side of the Blue Mountains the ainage is through a deep, wild canyon, which furnishes the finest enery that can be found in southeastern Washington. The river at excavated this canyon is the Grande Ronde—or, as it is usually lled by the inhabitants of that region, the "Grand Round"—a right, swift, winding stream that is walled in on either side by precices and mountain-like slopes 3,000 feet high. The canyon is not a arrow gash, for the upper portion of its inclosing walls have receded, nd side streams, most of them temporary rills, have cut a multitude f steep, lateral gorges, between which outstanding buttresses extend ar into the main gorge. In many places ridges that descend the oppote sides of the canyon overlap in its bottom and the stream makes harp curves in order to pass around their extremities. The main tributaries of the Grande Ronde, like Joseph Creek, which is indicated on ie accompanying map, have also sunk deeply into the basaltic tablend, as has each branch of these secondary streams. A great region at, but for the excavating power of the streams draining it, would e a flat-topped plateau, has been transformed into an intricate, ranching system of sharp-crested ridges, with profound gorges and anyons between. The general height of the land has thus been duced about 1,000 feet, but the sharp, angular mountains that have een sculptured out of the upraised block are so steep and their crests narrow that their loss in actual elevation is scarcely appreciated.

The canyon of Grande Ronde throughout the lower 20 or 30 miles its course is in general 2,700 feet deep. The distance between the rim rocks" bordering its walls is from 8 to 10 miles. The great ttresses that start from the main walls, however, extend far out to the canyon and make its width seem much less than it really is. hroughout the entire region drained by the Grande Ronde the ck, as in the lower plateau to the north of the Blue Mountains, is salt in horizontal sheets. Everywhere throughout the rugged walls at remain the horizontal courses of black basalt may be distinctly llowed. A magnificent example is thus furnished of the dissection an elevated plateau consisting of horizontal layers of hard rock by ie slow process of weathering and stream erosion.

A peculiar feature in the topography of the canyon of the Grande onde, and one which adds greatly to the interest of its wild scenery, the manner in which the spurs from the bordering mountain alls project into the gorge and overlap or dovetail. These lateral dges decrease in height from the borders of the canyon toward its ttom until a height of about 1,000 feet above the river is reached; ey are then prolonged at about the same level nearly across the

bottom of the canyon. The crests of the lateral spurs where they project far into the canyon are sharp and serrated and end in precipices. Between these interlocking spurs the river makes long bends and flows about these steep extremities in abrupt curves. The sharp, serrate ridges projecting from the north wall of the canyon frequently extend almost completely across the canyon and enter reentrant angles in the south wall. Between the cliffs forming the ends of these spurs and the precipitous and frequently apparently vertical south wall the river flows in a narrow, rocky channel.

It is impossible to describe briefly the peculiar topography of Grande Ronde Canyon so as to convey an idea of its ruggedness and of the many peculiarities due to the interlocking of lateral ridges just mentioned; but if we imagine the canyon as having been excavated to a depth about 1,000 feet less than at present and widened so as to be about 3 miles broad at the bottom, we shall have the general character of the upper gorge in mind. If over the nearly level floor of this wide-bottomed gorge we see the river winding from side to side, and at the ends of the southward curves cutting at the base of the cliffs bordering the valley on that side, and then fancy the region elevated a thousand feet, so as to give the stream renewed energy and allow it to cut a tortuous gorge in the bottom of the older valley, the ridges between the abrupt bends weathering to sharp crests and pinnacles, we shall be able to appreciate not only the characteristic features I have attempted to describe, but their mode of origin.

Two roads cross the canyon of Grande Ronde from north to south, but the excessive ruggedness of the canyon's bottom has thus far prevented the construction of even a safe bridle trail from east to west along the river.

Next to Snake River, Grande Ronde is the largest stream in southeastern Washington; but owing to the almost complete absence of bottom lands throughout that portion of its course which lies in Washington and for many miles south of the boundary, its waters can not be utilized for irrigation. Far south in Oregon the topography is different. Broad bottom lands there exist and the conditions are favorable for agriculture. Luxuriant bunch grass abounds, however, throughout the Blue Mountains and on the steep canyon sides. Stock raising is there the natural industry, but excellent fruit can be grown in all of the deeper valleys and gorges. In the gardens about the few houses and cabins that have been built by stockmen in the canyons of Grande Ronde and Joseph Creek vegetables of many kinds grow luxuriantly when properly irrigated, and tobacco plants as large and fine as any in Virginia or the Carolinas are now raised for domestic use.

Palouse River.—North of Snake River are a number of streams that head in the mountains of Idaho and flow westward in channels which increase progressively in depth, and finally become steep-sided canyons. The generally westward direction taken by these streams in

eir infancy and retained as they excavated their valleys and can-
ns in nearly horizontal sheets of basalt was determined by the gen-
westward inclination of the plateau—that is, they are consequent
eams.[1] These streams unite to form Palouse River, a tributary of
ake River. This river was not examined during the reconnoissance
ich furnished the basis of this report, but is understood to be com-
rable with the Walla Walla in size. Symons states, in the report
st referred to, that "the falls of the Palouse form another of the inter-
ing objects of this section. In the lower portion of its course the
louse flows through a deep fissure in the basaltic rocks, portions of
ich take fantastic forms, as towering pinnacles. At the falls the
er descends perpendicularly for about 120 feet into a narrow basin,
m which it flows off through its deep canyon for about 9 miles to the
ake River." The fall in the Palouse, whatever may be its history, is
narked exception to the even grade established by, I think, all asso-
ted streams, excepting Spokane River, and should claim attention,
t only from geographers, but from those interested practically in
ter power and irrigation. The abrupt change from a westerly to
southerly direction that the Palouse makes in its lower course is
rhaps due to a diversion of the river by the cutting back of a small
gh-grade stream flowing to Snake River. I fancy the falls have
me connection with such a capture of the low-grade and compara-
ely sluggish river by a smaller but more energetic rival.

Owing to the presence of sheets of clay and sand interleaved with
basalt in much of the region drained by the Palouse, springs are
merous along its branches, and supplement in an important manner
drainage from the mountains.

The broad plateau surface adjacent to the "Palouse country" on
south and west has not been visited by me, but, as shown on the
ps of the United States land survey, it drains westward. The
ble streams are frequently interrupted and small lakes are formed.
e origin of these lakes has not been explained, but the suggestion
made that the streams occupy old drainage channels that have been
rtially filled with sand and soil derived from the adjacent portions
the plateau. These lakelets are apparently similar in many ways
Moses Lake, in the Big Bend country, which is held by a dam
med of drifted sand.[2]

Spokane River.—Like the Snake, this river heads in the moun-
ns, well to the east of the basaltic plateau of southeastern Wash-
gton, and flows across it, much of the way in a deep canyon that
s been excavated in horizontal sheets of basalt. As in the case of

[1] It has been suggested by T. W. Symons, in a Report on the Upper Columbia River, Wash-
on, 1882, p. 116, that the streams here referred to have had their courses determined by
ders which moved in the general direction that they follow. My observations failed to sus-
this suggestion, as no evidence of the former presence of glacial ice was found anywhere in
heastern Washington.

[2] Bull. U. S. Geol. Survey No. 108, 1893, p. 96.

Snake River, also, the canyon of Spokane River was deeply filled with gravel at a recent episode in its history, and has since reexcavated its channel in part, making an inner steep-sided gorge in the gravels that fill the older and wider valley up to a certain level. When the stream renewed its work of excavation it did not flow in a straight course over its gravelly bed, but in curves. As the channel was deepened, projecting spurs of solid rock in the buried valley were discovered and had to be cut through before the modern gorge could be extended upstream. Some of the ledges of basalt that the stream met with as it progressed with its task of reexcavating have been cut through, but work is still in progress at one of them, as is shown at Spokane City. A curve in the course of the stream, when it began to clear out the gravels it had previously deposited, carried it across a buried ledge. This accident, as it may be termed, led to the growth of the thriving and beautiful city of Spokane.

A gauging station was established on this river at Spokane, Washington, in October, 1896, the gauge being at the bridge of the Oregon Railway and Navigation Company. The drainage area at this point is 4,005 square miles. A measurement made on August 27, 1896, by Mr. Cyrus C. Babb, when the water stood at a height of 2 feet, gave a discharge of 2,937 second-feet (cubic feet per second), while a later measurement, on October 17, 1896, at a gauge height of 1.46 feet, gave a discharge of 1,722 second-feet.

Precipitation formerly more abundant than now.—Throughout southeastern Washington there is abundant evidence that the rainfall was formerly greater than at present, and that the streams were larger and more numerous than we now find them. This is shown particularly in those portions of the plateau which are not crossed by streams flowing from the mountains to the eastward, as, for example, in the region with slopes leading to Deadman Creek, and over still larger portions of the plateau situated to the west and north of Palouse River. The valleys and canyons in the districts mentioned, while without question due to stream erosion, are disproportionally deep and wide in reference to the streams now occupying them. In many instances deep, trench-like valleys, such as streams are known to make, and which lead to similar valleys now occupied by water courses, are flat bottomed from side to side and entirely without drainage channels. Evidently in such instances there has been no surface drainage for a long term of years All the rain that falls is at once absorbed by the thirsty soil.

Similar evidence of a former period of greater humidity than the country now enjoys can be had throughout the basaltic region of southeastern and central Washington, as has been stated in a previous report.[1]

The time of the abundant precipitation, when the most marked of

[1] Bull. U. S. Geol. Survey No. 108.

what may be termed the secondary topographic features of the basaltic plateau came into existence, may for several reasons be considered as the Glacial epoch, when the higher mountains of Washington and Idaho were occupied by extensive snow fields and glaciers.

GEOLOGICAL FORMATIONS.

The geological problems presented in southeastern Washington are simple and easily understood. The rocks in this region fall conveniently in eight divisions. These are, briefly:

1. Crystalline and metamorphic rocks of unknown geological age, consisting principally of schists, gneisses, granites, and quartzites.

2. Dikes of igneous rock, which break through and are intimately associated with the metamorphic terranes just mentioned.

3. Coal-bearing sandstones and shales of Tertiary age, which form the surface at the eastern base of the Cascade Mountains and extend indefinitely eastward, may occur in southeastern Washington beneath the lava which forms the next group of rocks here enumerated.

4. Vast basaltic overflows, which cover all of the plateau region of central and southeastern Washington and extend widely into neighboring States. These rocks were poured out in a molten condition during what is known as the Tertiary period of geological history. This formation has been named the Columbia lava.

5. Interbedded with the sheets of basaltic rock composing the Columbia lava are beds of clay, sand, volcanic dust, and lapilli, which were deposited in part by streams and in part in lakes during intervals between the lava flows.

6. Above the Columbia lava in certain localities there are thick deposits of gravel, clay, and volcanic dust, constituting what is termed the John Day system. The rocks of this system were deposited in a Tertiary lake named Lake John Day.

7. In the canyons of Snake and Spokane rivers and along several of the more important secondary streams there are deposits of gravel and sand which were laid down by these streams after they had excavated their channels to their present depth.

8. As important as any of the rock groups just enumerated, but not usually classed as an independent geological formation, are the soils. Reference is here made especially to the deep, rich soils that mantle practically the entire surface of the Columbia lava. These soils are almost entirely a product of the disintegration and decay of the underlying basalt and represent what are termed residual soils. Mingled with the residue left by the decay and partial solution of the basalt is a minor quantity of volcanic dust which was blown out by some distant volcano and scattered widely over the land by the wind.

Each of the rock groups briefly enumerated extends far beyond the region treated in this report, and in part has been described in a previous publication.[1]

[1] Bull. U. S. Geol. Survey No. 108.

METAMORPHIC ROCKS.

In the report on a geological reconnoissance in central Washington, just referred to, there is a brief description of the crystalline rocks occurring in the mountainous region north of the Big Bend of the Columbia. From what little is known of the geology of northern Washington and western Idaho, it seems evident that this same great system of granites, schists, quartzites, etc., not only forms the mountains bordering the basaltic plateau, but to a considerable extent the floor beneath it. These ancient crystalline rocks were elevated into mountains and deeply eroded before the Columbia lava was poured out. The deep trench carved in the basaltic plateau by Snake River has revealed the underlying rocks at three localities.

Gneiss[1] *at Granite Point.*—The first exposure of metamorphic rock met with on ascending Snake River is about 24 miles below Lewiston and is known as Granite Point. The rock in the bottom of the canyon at this locality is granitic in character and is what is known commercially as "granite." More strictly speaking, however, it is a gneiss—that is, a rock having the same mineralogical composition as granite, but in which the minerals are arranged in bands and folia. The rock is dark in color, owing to the abundance of black mica scattered through it in irregular bands.

At Granite Point this rock is exposed on each side of the river for a distance of about 1,500 feet and rises to a height of 160 feet above the water. The canyon walls, rising fully 2,000 feet above the gneiss, are composed of the edges of horizontal sheets of basalt, and show the minimum depth to which the summit of the ancient hill, perhaps a prominent feature in old topography, was buried by the basaltic overflows.

The gneiss has been opened by quarrying to a depth of a few feet, but it is of dark color, of rather coarse texture, and has a foliated structure, which will probably preclude its use as a building stone except for rough masonry, such as the abutments of bridges, foundations, etc. The rock is fresh in appearance, and no products of disintegration mantle its surface. Evidently the portion exposed is the summit of an elevation from which, previous to the inundation of basalt, loosened fragments were carried away as rapidly as they originated. Both up and down stream from Granite Point for scores of miles the walls of the canyon are composed from bottom to top of horizontally bedded basalt. Downstream, however, especially on the left bank of the river, a westerly dip in the lower sheets of basalt, amounting to perhaps 2 degrees, can be detected. This is one of the few instances throughout the basaltic plateau to the north of the Blue

[1] The designation of this rock as a gneiss is from field notes and is provisional. There are reasons for believing it to be a quartz-diorite, and therefore igneous and not metamorphic in origin. This same remark applies also to the rock occurring at Granite Point, a few miles south of Pullman, mentioned on page 37.

Mountains in which any departure of the lava sheets from a horizontal position has been observed.

Schists at Buffalo Rock.—About 15 miles up the Snake River from the town of Asotin there is a locality known as Buffalo Rock,[1] which is of special geological interest. This locality can be reached conveniently from Asotin by following a road recently opened along the west side of the river and at the bases of the great precipices of basalt that form the canyon walls. Above Asotin the canyon of Snake River is deeper than below that locality and furnishes many striking exposures of columnar basalt, which rise tier on tier to a height of over 3,000 feet. In the neighborhood of Buffalo Rock, however, an important change occurs. The metamorphic rocks which formed the surface of the country before the vast inundation of molten lava took place again appear above the level of Snake River and rise at least 2,000 feet into the horizontally bedded basalt. The river has cut its gorge across a buried mountain so as to expose the rocks composing it for about a mile on each side of the stream. The horizontal layers of basalt abut against the steep sides of the old mountain and show no evidence of disturbance at the contact. It is evident that the lower rocks have not been forced upward into the basalt, but that the latter was poured out in successive sheets and flowed about a mountain of schist and finally overtopped its summit and buried it from sight. Additional overflows of the same character were spread over the site of the buried mountain and reached a thickness of fully 1,000 to 1,500 feet above its summit before Snake River began to excavate its canyon.

The sides of the buried mountain, where they first appear above the river, are steep and without talus slopes or other products of disintegration. Although 3,000 feet of horizontally bedded basalt are exposed in the canyon walls adjacent to the outcrops of schist, it is evident that the valleys of the old land lie below the level to which Snake River has corraded its channel.

Where the schists rise from the river and form the lower portion of the canyon walls, marked changes occur in the topography of the profound gorge. The horizontal lines and bands formed by the edges of lava sheets give place to apparently structureless walls, which are extremely precipitous. The schist is more resistant to atmospheric agencies than the basalt, and the gorge cut in it is narrow. Vertically above the schist the canyon widens, so as to make reentrant angles in its general course. This increase in the width of the gorge above the schist is especially conspicuous when viewed from its borders.

The rocks which cause these important changes in the character of the canyon are mostly greenish, spotted schists, and are evidently

[1] The name, I have been informed, refers to certain rock inscriptions made by Indians, some of which are thought to represent buffalo. A large rock on the west side of the river is covered with figures made by pounding the surface with a dull instrument, probably a pebble. Similar designs are said to occur also on the rocks of the opposite shore.

of sedimentary origin, as well-rounded pebbles and angular masses of rock may still be recognized in them. Samples may be collected showing a transition from conglomerate, in which the pebbles are still prominent, through schistose rock containing flattened and elongated pebbles, to greenish schist with spots and blotches due to altered pebbles, and from these, again, to fine, even-grained, silky schists of uniform color. Near the southern end of the exposure there are rocks of plutonic origin[1] which appear to be dikes breaking through the schist, but as a similar rock occurs as pebbles in the schist, it is evident that at least some of the intrusives were formed before the material since metamorphosed was deposited.

The schists are traversed by small veins of quartz, which are probably gold bearing, as gold is obtained by placer mining in the gravels and talus slope bordering the river. What success has attended these mining operations I was unable to learn during my brief visit. No true fissure veins were seen in the schists, and from such examinations as I was able to make it seems doubtful if quartz mining will ever be profitable.

Schists at Wild Goose Creek.—Upstream from Buffalo Rock one may follow the river by a bridle trail to beyond the mouth of Grande Ronde River, a distance of about 8 miles. Throughout this portion of the canyon the walls are precipitous, frequently rising in sheer cliffs, and are composed from base to summit of horizontally bedded basalt. The canyon walls increase in height as we ascend the river, and at the mouth of the Grande Ronde are about 4,000 feet high. The actual margins of the canyon, however, recede from the river, and it is only when one gains a commanding point on the rim of the vast gorge, like the summit of Mount Wilson, for example, that its full grandeur is revealed.

Just above the mouth of the Grande Ronde metamorphic rocks again rise above the level of the river and form a large part of the canyon walls for at least a score of miles. The full extent of this fine exposure is not known, but it is prolonged far to the south of the southern boundary of Washington. The metamorphic rocks appear suddenly above the level of the river at a locality about a mile south of the mouth of the Grande Ronde, and rise from the water in what appear to be vertical precipices to a height of approximately 2,500 feet.

The leading phenomena presented at Granite Point and Buffalo Rock are here repeated, but on a grander scale. The horizontal basalt abuts against cliffs of schist, and shows no change at the contact. The sides of the buried mountain range, as seen in section in the canyon walls, are precipitous. On the east side of the river, where the schist first appears as one journeys upstream, the buried

[1] Thin sections of this rock have been examined by Mr. J. S. Diller, who states that it is a porphyry, composed chiefly of granular quartz with much biotite, forming a groundmass in which are embedded phenocrysts of quartz and feldspar, chiefly plagioclase.

ıountain side slopes about 45°, and is free of débris. The base f the mountain is evidently far below the level of Snake River. ach successive layer of basalt extended farther and farther over the ietamorphic rocks, until at a height of about 2,500 feet the summit of ıe range is covered. The horizontally bedded lava above the highest eak of the buried mountain is not less than 1,500 feet thick. A ear section of fully 4,000 feet of horizontally bedded lava sheets is ıere exposed, but the base of the pile is not seen.

The metamorphic rocks that appear beneath the basalt between the ıouth of Grande Ronde River and Wild Goose Creek were only astily examined, and attention can only be given at this time to their ıore general features.

The rocks are plainly of sedimentary origin, as their stratification ı prominent. They have a thickness of several thousand feet. The trata in the northern part of the section are inclined northward at n angle of 40° to 45°, and in places are nearly vertical. A great ome of ancient rocks has been cut through. The upper layers of he dome are thin-bedded siliceous limestone containing indefinite ossils;[1] beneath this are thick layers of thinly laminate, granular imestone, containing some silt and organic matter, which appear in onspicuous white ledges. This rests on schists that show a diversity f colors, varying from green to red, and are frequently fine and ilky in appearance. Marked contrasts are apparent in the schists, ome layers being schistose conglomerates or breccias, while others esemble the finest roofing slate. The schist has great thickness, and ı believed to rest on granite. The lower contact of the schist was ot seen, but granite occurs abundantly in the pebbles along Snake iver, and is reported by miners to come to the surface a short disance above Wild Goose Creek. The topography in that region bears ut this statement.

No more than a hasty outline of the character of the rocks here eferred to is possible at this time, as my opportunities for observaion were, for several reasons, very limited. It seems evident, howver, that a broad uplift, with a granite core, passing upward into chist and then again into but moderately altered limestones, was uried beneath the basalt and again exposed and deeply dissected by rosion. The geologic age of the schists and limestone is unknown, ut a careful search in the limestone would very likely reveal fossils y which it might be determined.

Standing on the summit of Mount Wilson, which is a remnant of ıe basaltic plateau left isolated by the cutting of the canyon of Snake

[1] Samples of this limestone have been studied by Mr. J. S. Diller, who reports that thin sections examined under the microscope "do not show fossil forms nearly so distinctly as the weathered surfaces. The specimen was shown to Mr. G. H. Girty, and he agrees with me not ly that the fossils are crinoids, but that one of them has a pentagonal stem. Crinoids with ms of this sort are not definitely known to be older than the Permian, and it is probable at this one is considerably later. The specimens examined look very much like the Triassic estone of California, in which fossils are abundant."

River and the much narrower but nearly as deep gorges of Joseph Creek and Grande Ronde River, one may command a far-reaching view of the deeply dissected region about, and may read the leading facts in its geological history as plainly as from a printed page.

Eastward from Mount Wilson one beholds the deepest and wildest portion of Snake River Canyon. Fully 50 miles of the great gorge are in full view. To one familiar with the narrow, trench-like character of the same canyon for 100 miles or more below Lewiston, it is at once apparent that marked variations in nearly all its features accompany the change produced by the unearthing of the buried mountain range already briefly described. The canyon is deeper, also, than farther downstream, for the reason that Snake River has here cut across the flank of the Blue Mountain uplift. Where the metamorphic rocks form a large portion of the canyon walls the excavation is probably four or five times as wide as where it is cut wholly in basalt. The distance from the remnant of the old plateau surface forming Mount Wilson across the canyon to the fringe of pines growing on the crest of the opposite wall is, by estimate, fully 15 miles. In this interval there is what seems at first a bewildering maze of mountain-like ridges, palisades, towers, and battlements. Many of the forms are strikingly architectural in appearance. Vast buttresses of schistose rock, rising precipitously from the depths of the canyon, form the basements of huge castle-like masses of basalt, in which the horizontal bedding resembles courses of cyclopean masonry. The student of topographic forms sees at a glance that not only the more prominent features of the rugged landscape, but the details in the sculpturing of the seeming castles and palaces conform to well-known laws of erosion, weathering, and rock structure. In the upper portion of the canyon walls the horizontal bands formed by the edge of lava sheets may be traced on either hand as far as the eye can reach. Many of the lava sheets are columnar. The long colonnades, lessening in perspective, may be followed into each alcove and lateral gorge, and far out on the buttressing ridges. At the ends of many of the spurs there are groups of towers and pinnacles formed of the ruins of isolated masses of columnar rock.

Below the basalt are sharp crests and ridges rising between lateral gorges that lead down from the battlements above to the silvery thread formed by the river in the depths below. In the lower portions of the canyon walls, where schists and granite are exposed, the prevailing lines are vertical, and are due to the erosion of lateral streams and rills. Where the lateral ridges approach the river they end in precipices, which frequently descend nearly vertically for a thousand feet to the water's edge. At such localities there is no room for one to pass between the river and the towering cliffs. It is the abruptness with which the lateral spurs plunge down to the river that gives the vast gorge much of its canyon-like character.

In breadth and depth and in the multitude of details this canyon is comparable with the greatest of all canyons in North America, namely, the Grand Canyon of the Colorado. One of the greatest charms in the wonderful scenery of the Colorado, however, is wanting in Snake River Canyon, namely, the varied and brilliant coloring. The canyon of Snake River is dark and somber. The black and brown of weathered basalt and the dull gray of schist and granite find scarcely any relief from brighter colors. The pleasing tints imparted to the scenery of many regions by the iron oxides in residual soils are absent. The vegetation is too scanty to mask the angular forms or enliven the somber tones of the rocks, although the massive cliffs are in places veneered with yellow lichens, and in the lateral gorges, where springs well out, there are faint lines of verdure. In autumn these thickets of willow, haw, and roses assume brilliant hues. The talus slopes between the horizontal cliffs of basalt, as well as the surfaces of the ridges and domes of schist and granite, are clothed with bunch grass, which gives to them a silvery sheen that is ever changing when the wind blows.

On looking across Snake River Canyon from the summit of Mount Wilson, the junction of the horizontally bedded basalt with the schists and granite beneath can be distinctly traced for a score of miles. The crest line of the buried mountain is rugged and serrate. The gorges between the higher crests and spires are filled with horizontal sheets of basalt, showing that the fiery flood flowed about the ancient peaks, leaving them for a time as islands in a sea of molten rock, and then overtopped their summits and completely buried them from sight. This impressive spectacle of what was once a sharp-crested mountain range, rising at least 2,500 feet and probably more than 3,000 feet above the adjacent valleys, and subsequently buried beneath horizontal sheets of molten rocks, and ages later revealed by the slow down-cutting of a river canyon, is one of the most instructive lessons that the student of geology and geography will find anywhere in the world.

Glancing westward from Mount Wilson into the magnificent canyon of Grande Ronde, which has been excavated in the Blue Mountain uplift, one sees at least a thousand feet of horizontally bedded basalt which lies above the level of the summit on which one stands. The Columbia lava is, therefore, not less than 5,000 feet thick. Of its maximum thickness we have as yet no measure.

But to return to the metamorphic rock. No granite was found by me in the canyon of Snake River; but, as already stated, it is reported to occur a little above the mouth of Wild Goose Creek—that is, to the south of the point where the Washington-Oregon boundary meets the river. In the canyon walls, as we have seen, the basalt is clearly distinguishable from the rocks beneath it. The schists also have topographic forms of their own, in which the bedding, now highly inclined, and the joint planes play an important

part. As the eye ranges along the cliffs bordering Snake River upstream from the mouth of Grande Ronde, a marked change is apparent in the sculpturing of the older rock-series a few miles south of Mount Wilson. The sharp crests and steeply inclined bedding planes of the schist there give place to rounded domes and hillocks. The immediate banks of the river are precipitous, but at a height of perhaps a thousand feet above the water the slopes are more gentle, and a rude terrace with rounded curves and flowing outlines, some 3 or 4 miles broad, leads to the cliffs of basalt which define the upper margin of the canyon. The forms seen on the terrace-like slopes are such as are familiar in many localities where granite is the surface rock and where weathering is far advanced. Further exploration in this interesting region will probably show that the series of limestone, schist, etc., already briefly described, rests on granite, and that for many miles along the boundary between Oregon and Idaho this rock will be found in the immediate banks of Snake River. I have spoken of the rocks beneath the basalt as belonging mainly to the metamorphic series, but whether this granite is a sedimentary rock changed by heat and pressure or is of igneous origin I leave others to discover.

The schists exposed in Snake River Canyon, like the similar rocks a few miles farther downstream, are traversed in every direction by small segregated quartz veins, which have been reported to be gold bearing. Several mining claims have been located along the canyon wall on each side of the river, but whether any of these will repay mining is not known. From a knowledge of similar rocks elsewhere the value of these mines seems doubtful. In the alluvial deposits along Snake River at the mouths of lateral gorges in the schists, placer mining has been carried on from time to time for several years. Hydraulic mining on a small scale has been attempted, but with what success I am unable to state.

Granite, schist, quartzite, etc., north of Snake River.—The eastern boundary of Washington to the north of Snake River cuts across the foothills of the mountains of Idaho, leaving some of the ridges and outstanding buttes to the west of the line. The geology of western Idaho is as yet unwritten, but, as shown by the sand and gravel in the streams which enter Washington, the rocks to the eastward include granite, gneiss, quartzite, diorite, etc. Mountains consisting largely of these rocks form the eastern limit of the overflows of Columbia lava in the region here considered. The great basaltic plateau meets the mountains in a sinuous line which in a general way coincides with the interstate boundary. The mountains along this boundary resemble a rugged coast line, but the sea is replaced by the plateau of lava. Rounded and weather-beaten capes and promontories on the shore of the lava sea project into the wheat lands of the plateau and a few islands of quartzite break the monotony of its surface.

To term the rolling prairie lands of the "Palouse country" a sea and the hills to the eastward its rugged shore is not entirely a rhetorical

figure. The basalt forming the vast plateau was once molten and flowed over the land in successive inundations of liquid rock. The plateau was then a sea of fire. As sheet after sheet of molten rock was spread out, the floods rose higher and higher on the rock-bound coast. Valleys and embayments in the mountains were flooded and now have level floors of basalt. The eastern limit of the region covered by these fiery inundations is sharply defined not only by the topography but by the junction of the wheat fields which flourish on the soil formed by the decay of the lava with the uncultivated uplands.

The lavas are less deep in the neighborhood of the mountains than farther westward, and at one locality at least have been cut through by stream erosion so as to expose the granitic rocks beneath. At what is known as Granite Point, on the Northern Pacific Railroad, about 8 miles southeast of Pullman, in township 13, range 6, a few hundred square feet of gneiss (?) may be seen in the bottom of a shallow valley. This rock has been quarried in a small way and found serviceable for rough masonry. It is somewhat weathered, but the usual products of long-continued disintegration and decay are absent. The shape of the rock surface exposed and the absence of débris on it suggest that it is the summit of a hill from which all loose material had been removed before the floods of lava buried it from sight. The rock at this locality is of the same character as that already mentioned as occurring at Granite Point, in Snake River Canyon, about 10 miles distant. The difference in elevation between these two exposures of the old land surface beneath the basalt is approximately 2,000 feet. This is one of many observations which indicate the roughness of much of the country which was changed to a level plateau by the basaltic overflows.

The most striking evidence, however, of the ruggedness of the topography of the buried land and of the ocean-like character of the inundation of molten rock that flowed over it is furnished by the old mountain peaks, that now rise as islands above the yellow wheat lands. These islands are within a few miles of the border of the basaltic overflows. All of the old landmarks where the basalt is deepest are completely buried. Islands of granite surrounded by basalt, near the northern border of the plateau, in the neighborhood of the Grand Coulée, in the Big Bend country, were described in a previous report[1] but far more impressive examples of the same general character are furnished by Kamiack and Steptoe buttes in the Palouse country.

Kamiack Butte.—In Whitman County, 9 miles north of the town of Pullman, there stands a picturesque hill of quartzite and of quartzose conglomerate rising 500 or 600 feet above the surface of the surrounding basaltic plateau. This is the summit of a bold hill that was completely surrounded by the inundations of molten rock.

[1] Bull. U. S. Geol. Survey No. 108, 1893, p. 90.

The soil on Kamiack Butte is sandy and was derived from the disintegration of the underlying rock. It differs in a marked way from the soil of the adjacent wheat lands. There is no evidence to show that the basalt ever covered the butte, although it rose between 100 and 200 feet higher than the present plateau surface. The lowering of the surface of the plateau is due to the disintegration and decay of the basalt and the removal by stream and wind erosion of some of the fine soil thus produced. It is an instructive fact, as will be noted in advance in considering the origin of the low hills of the originally level plateau surface, that the soil of the plateau has not been blown over the rocks forming the butte.

To the southwest of Kamiack Butte and about 2 miles distant is another but lower elevation of the same character. To the eastward, also, there is a range of hills, apparently composed of quartzite, which extends into Idaho, and is of the nature of a cape projecting into the sea of formerly molten rock. The extremity of this ancient headland is separated from Kamiack Butte by 2 or 3 miles of basalt.

Steptoe Butte.—This remarkable feature in the relief of eastern Washington is situated in Whitman County, 8 miles west of the town of Garfield, and 10 or 12 miles from the hills which bound the basaltic plateau on the east. It rises between 1,000 and 1,100 feet above the plateau which surrounds it on all sides. From every direction, over a wide extent of country, the butte is a prominent landmark, and from whatever point of view it is seen it appears as a steep-sided and sharp-pointed pyramid. When viewed from the eastward, its southern slope makes an angle of 18° and its northern sides an angle of 19° or 20° with a vertical line. Each side is gently concave and gives to the eminence the appearance of a volcanic cone. The slopes on all sides except the west, which is easiest of ascent, are about as steep as is shown by the measurements just given.

Steptoe Butte, like its lesser companion described above, is composed mainly of quartzite, but at the summit the rock has the character of a quartz-schist. Its sides are not encumbered with loose débris, and but little soil has formed from the disintegration of the hard, resistant rock. It is plainly the summit of a bold mountain peak, the base of which was deeply buried by the overflows of lava that surrounded it and left it as an island.

The instructive panorama spread before an observer on Steptoe Butte leads naturally to a digression from the study of the geology of the butte itself. From this commanding summit we can with advantage, I think, review some of the leading features in the geography of the region under consideration.

To accommodate tourists, a commodious hotel has been built on the apex of the great pyramid. From about the hotel we may in an hour obtain a far more graphic idea of the characteristics of the surrounding region than days of travel across the plateau and over the neigh-

ng mountains would furnish. In all directions from the base of butte extend the vast wheat lands of the basaltic plateau, which seemingly as level as the sea. The short hills and level-floored ressions on the surface of the plateau enhance rather than detract n this resemblance. It is a stormy sea, but none of the wave-like s rise above a certain general level. The distant horizon is undu- ng, like the sky line on the ocean after a storm. The view to the h, west, and southwest is limitless. Not a single landmark rises ve the general level of the roughened plain. Far away to the h a long, low arch, forming a silhouette in blue against the sky, als the outline of the Blue Mountains. The base line of the arch) or 40 miles long, and the height of its crest not over 1,200 or 0 feet above the general level of the intervening plateau. We w that in the vast plain that extends to the Blue Mountains there deep canyon through which Snake River flows, but it is only er exceptionally favorable conditions of the atmosphere that its rse, easily mistaken for the shadow of a passing cloud, can be ed through the yellow wheat fields. To the eastward one sees the k forest-covered hills and mountains of Idaho, and can trace sinuous line formed by the junction of the intervening plateau n the highlands that determine its border. Each level-floored inlet embayment is yellow with grain and each headland dark with s. These and other features of the border of the once molten of lava can be as easily recognized as the inlets and headlands of coast of Maine when viewed from the summit of Mount Desert nd.

efore the rich soil of southeastern Washington was furrowed by plow it was covered with bunch grass, but destitute of trees and ubs. At present practically every acre of the plateau surface is er cultivation. The observer on the summit of Steptoe Butte ts down on a limitless patchwork of brown and yellow. The wn is the soil of fallow land, the yellow the golden of the wheat ls. It is the custom to take but one crop from the land in two rs, so that each summer practically half of the land lies fallow. yellow grain fields and the brown, plowed lands are interspersed n each other as far away over the plateau as the eye can reach. ough there are thousands of farmhouses in the field of view, they nestled in valleys and hollows, and only a few near the immediate of the butte are in sight.

ext to the boundless expanse of the level plateau, the most inter- ng feature of the landscape is furnished by the wave-like hills and amless depressions that give diversity to the grain fields. When sited Steptoe Butte late in September the wheat had been har- ed, and the paths of the reapers surrounded the hills like the our lines on a map and served to accent the peculiarities of their ns. The origin of the hills, however, and the nature of the deep,

rich soil of which they are composed can be better understood from a nearer inspection and will be discussed later. Let us now return to our study of the ancient crystalline rocks.

The uplands, consisting largely of quartzite and granitic rocks which occur north of Snake River along the general course of the Washington-Idaho boundary, swing westward near Spokane and form the mountainous region of northeastern and northern Washington. This region is known in an indefinite way as the "Okanogan country." As described in Bulletin No. 108, the Columbia River in making its wide detour termed the "Big Bend" follows the base of the mountains that determine the northern border of the basaltic plateau. The same great series of crystalline rocks is continued westward and forms the mountain about Lake Chelan and the northern part of the Cascade range. Much of this region of crystalline rocks is rich in minerals, and excellent building stone abounds. This most promising field for geological study awaits exploration.

KITTITAS SYSTEM.

In west-central Washington, notably in Kittitas County and crossing the Columbia at Wenatchee, there is an important system of sandstones and shales carrying valuable beds of coal, which rests on the series of ancient crystalline rocks described above, and is covered in part by the lavas next to claim attention. The coal mines at Roslyn are in this system.

In Bulletin No. 108 I have proposed the name of Kittitas system for these coal-bearing rocks, for the reason that they form the surface over a large part of Kittitas County. The rocks of this system have not been studied and their boundaries are unknown, but in the central part of Kittitas County they pass beneath the series of lava sheets forming the basaltic plateau of central and southeastern Washington, and may possibly extend beneath the region described in this report. No outcrops of the rocks of the Kittitas system are known, however, east of the Columbia, except in the neighborhood of Wenatchee, but it is not improbable that they extend somewhat widely beneath the lava rock of the central basin.

COLUMBIA LAVA.

As already stated, the great basin between the mountains of Idaho and the Cascade range, including what is known as the "Big Bend country," or the Great Plains of the Columbia, and all of the southeastern portion of Washington, is covered with what is termed, in a general way, lava rock. Since a convenient geographical name for this lava is desirable, I have suggested the term "Columbia lava," for the reason that much of the country covered by it is drained by the Columbia River and its branches.[1]

Origin.—The Columbia lava was poured out from openings in the

[1] Bull. U. S. Geological Survey No. 108, 1893, p. 21.

arth's crust in a molten condition, in much the same manner that olcanoes at the present day are discharging similar material. It robably came from fissures in the earth's crust, however, instead of rom individual vents, as in the case of Mount Rainier, for example, nd spread away from the fissure in highly liquid sheets, which lowed rapidly.

As is shown wherever canyons have been cut in the Columbia lava, t is not one vast flow, but is composed of many beds, frequently from 0 to more than 150 feet in thickness, which are separated by scoria- eous layers and other partings. The surfaces of flows which cooled efore the next sheet above was poured out are frequently rough and f a cellular or scoriaceous character and are occasionally covered ith lapilli, as well as with widely extended layers of clay and sand nd old soils.

The statement that the lava was poured out through fissures is based n part upon an hypothesis which is held for the reason that the fea- ures characteristic of volcanoes are absent and no plausible account f the origin of the lava, except by "fissure eruptions," has been sug- gested. The fissures through which the lava is supposed to have reached the surface would be filled with similar material and would give origin on cooling to what are known as dikes. At one locality in Kittitas County, where the rocks beneath the lava have been exposed by erosion, large dikes of this nature have been seen.[1] This observa- tion is in direct support of the fissure-eruption hypothesis. The large number of separate sheets of lava, however, demand under the hypothesis mentioned that the earlier overflow should have been broken by fissures, in order to admit of the escape from below of the molten material which rose and overflowed the surface so as to form the later sheets. Dikes should therefore be expected to occur in the lower sheets of lava leading up to the superior layers. Although the Columbia lava has been deeply dissected by stream erosion, only three or four dikes cutting across the layers have been seen. These are situated in the walls of Grande Ronde canyon and are all small, the largest being only about 30 feet thick. Whether these dikes lead to lava sheets higher in the canyon wall and indicate the fissures from which material forming the superior sheets was derived is not certain, for the reason that disintegration has obscured the upward extension of the dikes and made it impossible to trace them for more thar a few hundred feet above the present level of Grande Ronde River.

Throughout the hundreds of miles of cliffs formed by the walls of stream channels through the Columbia lava that have come under ny notice, with the exception of the locality just mentioned, dikes are bsent. There is thus seemingly a weakness in the evidence which hould be looked for in support of the fissure-eruption hypothesis,

[1] Bull. U. S. Geol. Survey No. 108, 1893, pp. 67-68.

but this may be removed when the region covered by the Columbia lava, especially in the vicinity of the Cascade Mountains, is more extensively examined.

Extent.—The Columbia lava is by far the most extensive of the geological formations in the far Northwest. It is also the most important from an economic point of view, since by the disintegration and decay of its surface layers it has furnished the wonderfully rich soil on which a large portion of the grain of Washington and adjacent States is raised.

The boundary of this great series of volcanic overflows in eastern Washington, from Snake River northward to Spokane River, and thence westward along the Columbia, has already been briefly described. The Columbia lava occurs also in the Cascade Mountains of Washington and Oregon, and extends southward into California. To the east of the Cascade Mountains it occupies much of Oregon and large portions of southern Idaho. Although its boundaries have not been mapped, it is known to occupy an area of not less than 200,000, and possibly as much as 250,000, square miles.

Thickness.—The Columbia lava, as already stated, was poured out in a molten condition and spread over the country like a series of fiery inundations. The surfaces of the various sheets were originally practically horizontal, but the surface of the inundate country was uneven and, in part at least, mountainous. The depth of the hardened lava at various localities would therefore depend on the character of the topography of the region it covers. The original thickness has been decreased by erosion, but, except in the canyon, this is not great. The loss from the surface of those portions which have not been upraised or tilted is, under the most liberal estimate, not over a few hundred feet.

The maximum thickness of the lava, or, considering it as a congealed sea of molten rock, the deepest sounding, is not known. About the margin of the basaltic flows along the Columbia River, in the "Big Bend country," canyons 300 or 400 feet in depth reveal the granite beneath. Along Snake River Canyon for over 100 miles from its mouth 2,000 feet of lava is in sight. Where Snake River and the Grande Ronde cut into the Blue Mountain uplift, between 4,000 and 5,000 feet of horizontally bedded lava is exposed. This is the deepest section yet discovered, but even there the base of the series is not seen. It seems safe to conclude that the maximum thickness is in excess of 5,000 feet. In the Cascade Mountains, according to Prof. Joseph Le Conte, 3,700 feet of lava is to be seen. From my own observations in that region, however, I should not be surprised if much greater thicknesses are discovered. The average thickness for the Columbia lava in the State of Washington was thought by Lieutenant Symons[1] to be not far from 2,000 feet. In a former report I was dis-

[1] Bull. U. S. Geol. Survey No. 108, 1893, p. 21.

osed to agree with this estimate, but observations since made along nake River certainly indicate that the average thickness over large reas must be much in excess of the amount stated. Estimates of the verage thickness can at present have but little value, however, as ven single measurements of the total thickness are lacking, except ear the borders of the lava-covered region.

Character of the rock.—The general appearance of the rock forming he widely extended formation under discussion is familiar to everyne in southeastern Washington. It is the common black rock of the ountry. It underlies all of the wheat lands, and is splendidly xposed in the canyons of the Grande Ronde, Snake, Palouse, and pokane rivers, and along nearly all of their branches west of the Vashington-Idaho boundary. To the geologist this rock is known as asalt.[1] It is dark, usually black, in color, but various tints of ray, green, brown, and red are not uncommon. Most of the variaions from the normal black or nearly black color are due to weathring. The upper surfaces of some of the sheets, however, are red, wing to the oxidation of the iron in the rock while it was yet highly eated.

One of the latest lava flows in the great series here considered occurs Yakima County, between Cowiche and Natches creeks, and differs om all other portions of the Columbia lava now known. The lava eet referred to consists of what is termed hypersthene-andesite, and ntains prominent crystals of the mineral hypersthene.[2] When the olumbia lava is critically studied, it is probable that other rocks early related to basalt, but differing from it in chemical and mineogical composition, will be discovered.

Except when the molten magma cooled with excessive rapidity, as coming in contact with water, or flowed over wet sands and clays, e material composing it became crystallized. The slower the coolg, the larger the crystals that were formed. The central portions the various sheets are for this reason usually coarser in texture an their surfaces. In a few instances the bottom of a layer is lmost glassy for an inch or two in thickness, owing to sudden cooling. ragmental material, sometimes found in sheets between the layers, nd probably formed by the disintegration of the highly heated rock n coming in contact with water, is also excessively fine grained and itreous in luster.

The crystals of which the basalt is composed can seldom be seen by ne unaided eye, but when thin sections of the rock are studied with

[1] A characteristic sample of this rock from Mill Creek, near Walla Walla, has been examined y Mr. J. S. Diller, who reports as follows concerning it: "The rock is a characteristic basalt, mposed of plagioclase feldspar, augite, olivine, and magnetite, with considerable globulitic ass. The feldspars are well developed, with crystallographic boundaries. The augite is less ell developed and is generally granular, as is also the olivine. The magnetite is mostly in octaedral crystals, which for the most part are arranged in groups made up of lines perpendicular one another. The rock is perfectly fresh and unaltered."

[2] Bull. U. S. Geol. Survey No. 108, 1893, pp. 64-65.

the assistance of a microscope their nature is clearly shown. The minerals which make up the bulk of the rock are feldspar, augite, olivine, and magnetite, and crystals of other minerals are scattered thickly through uncrystallized portions of the magma, which forms a glassy groundmass. The minerals mentioned are silicates of alumina, magnesia, soda, potash, lime, iron, etc., and when the rock decomposes on weathering these substances are more or less perfectly liberated.

Chemical analyses of basalt show that in general it contains from 46 to 57 per cent of silica and from 11 to 22 per cent of alumina, together with lime, magnesia, potash, etc., in proportions varying from a small fraction of 1 per cent to over 10 per cent. It is the presence of lime, potash, and phosphoric acid in the basalt that gives the soils formed from its decay much of their richness for agricultural purposes.

Columnar structure.—The columnar structure of many of the lava sheets gives interesting details to the massive architecture of the canyon walls at many localities. This structure, as is well known, is due to the shrinking of the rocks on cooling. The columns have their longer axes at right angles to the cooling surfaces, and consequently, in horizontal sheets, are vertical. When a canyon is cut through a series of beds having this columnar structure, the section of each layer presents the appearance of a long colonnade of closely set vertical shafts.

The columns are most commonly hexagonal in cross section, although other forms, with sides ranging from three to eight, may be found. They are frequently 3 or 4 feet in diameter, but sometimes larger, and from a few feet to 30 feet or more in height. The larger columns are not usually sharply defined, as their sides are apt to be irregular. The most perfect examples have usually a diameter of from 15 to 25 inches. One of the best displays of columnar structure that I have seen occurs on the left bank of Snake River, about 3 miles above the mouth of Alpowa Creek. A long colonnade is there exposed, forming a vertical wall 30 to 40 feet high, in which the shafts are remarkably even and of uniform size. The columns are mostly six-sided and about 14 inches in diameter. Beneath this columnar layer is a bed of pure-white volcanic dust. The removal of this soft layer by the river has led to the undermining of the heavy sheet of basalt resting on it and the breaking away of the jointed rock, so as to form the wall in which the columnar structure is so well displayed.

The breaking of the basalt into columns is due, as stated above, to shrinkage on cooling. Breaks in the rock, termed joints, are thus formed. These are best developed when cooling is slow, and for this reason the central portions of lava sheets are frequently regularly jointed—that is, divided into well-defined columns—while the top and bottom portions of the sheets are confusedly jointed, and sepa-

rate into blocks of all shapes and many sizes. The irregularly jointed rock does not fall apart so readily as that in which the joints are parallel and well developed. It is for this reason that the rows of columns exposed in the canyon walls so frequently rise from a projecting base and support an overhanging cornice above.

In some localities, particularly where the basaltic columns are of large size, their surfaces present a network of grooves looking like the cracks formed in the surface of mud on drying. The origin of these peculiar markings was not apparent until weathered surfaces were examined. It was then found that the columns frequently have a well-defined internal structure. They are formed of small columns similar in form to the main shafts, but usually only an inch or two in diameter. These secondary columns radiate from a confusedly jointed central core and terminate in more or less regularly shaped prisms at the surface of the main column. It is the junction of the bounding planes of the secondary columns with the surface of the main shafts that gives rise to the peculiar figures mentioned above. These figures, frequently six-sided, but usually irregular, are best seen when the surfaces of the main columns are somewhat weathered. The cracks or planes of jointing that define the sides of the large columns are, as already stated, at right angles to the cooling surfaces. The secondary columns are at right angles to the master joints, which determined the cooling surfaces of the material forming the columns bounded by them.

The best locality for studying this secondary columnar structure that I have noticed is on the left bank of Snake River, about 6 miles above Asotin, where an excavation for a road has recently been made at the base of a great precipice.

The sides of the columns into which the Columbia lava has so frequently been broken seldom present plane surfaces, but are irregular in many ways. The convexities on the side of one column fit accurately into depressions in the sides of the adjacent columns and serve to lock the columns together, and thus admit of their standing in vertical precipices. The columns in the face of a cliff are frequently so loose that one can move them with the hand, but the interlocking of their irregular sides with their neighbors holds them in place.

The series of vertical joints which divide the horizontal sheets of basalt into columns are frequently crossed by other joints or breaks, which are horizontal. There are at least two classes of these horizontal joints, one of which affects individual columns, while the other runs through a large series of columns.

The cross joints which affect individual columns break them into sections from a few inches to perhaps 3 or 4 feet in length. The summit of each section is commonly concave, or depressed, so as to form a saucer-shaped hollow, into which fit the rounded ends of the sections next above. It is seldom, however, that this ball-and-socket

cause the variations in the character of the silica deposited in cavities in the lava, one may hope to find the variety having brilliant colors at almost any locality.

Extent and thickness of individual sheets.—In the walls of many of the canyons that have been excavated in the balsatic plateau, and especially in Snake River Canyon and along Spokane and Columbia rivers, individual layers of lava may be traced for miles, and even for scores of miles, without notable variation in thickness or in general characteristics. I have not made continuous journeys of more than 25 or 30 miles through the canyons, but have entered them at various places. Localities on their brinks frequently command a view of 10 or 15 miles of the opposite wall, and from exceptionally favorable localities for observation, like the summit of Mount Wilson, the edges of the lava sheets may be seen clearly exposed for not less than 40 miles. In no instance have I seen a lava sheet thin out or in fact present any marked variations. It is evident that the lava was highly fluid at the time of its extrusion, and that it spread widely over the country in horizontal sheets of remarkably uniform thickness. Few exact measures of the thickness of individual sheets have been made, but by eye estimates it is safe to say that many sheets are from 40 to 60 feet thick, and not infrequently layers of more than double these amounts occur. The average thickness, I should judge, would be 60 or 80 feet.

Number of overflows.—In almost any view of the walls of Snake River Canyon, which furnishes the best section known of the Columbia, 50 or 60 well-defined bands may be seen, which at first sight appear to be the edges of individual lava sheets. A closer examination will show, however, that some of even the most conspicuous horizontal partings do not mark the junction of separate lava sheets, but are due to the horizontal jointing already described. Some of the bands, too, are due to the columnar structure of the central portion of the various sheets adjacent to other portions of the same flows which are confusedly jointed. For these reasons, and also because the terraces or steps in the canyon walls are covered with loose rocks and soil, banked high against the cliffs above, it is difficult to determine how many individual lava sheets have been cut through in order to form the canyon. Reliable evidence of the vertical extent of the individual sheets of lava is sometimes furnished by interbedded layers of sedimentary origin, like sand and clay, and also by sheets of fragmental material, termed lapilli and volcanic dust. It is infrequent, however, in eastern Washington that evidence of this nature can be had. Usually, the only safe method of distinguishing the individual flow is by noting the occurrence of scoriaceous bands.

On counting the numbers of scoriaceous bands exposed in the walls of Snake River Canyon, I found that at least eight lava sheets had been cut through to form the canyon where it is 3,000 feet deep. I am by

The upper surfaces of the various sheets are characterized especially by a cellular or scoriaceous condition; the under surfaces also have the same characteristics, although usually not so well marked. As a lava stream advances, its surface becomes cooled and forms a scoriaceous crust, which may be sustained for a time on the still moving and highly liquid lava beneath. A hardened crust also forms on the extremity of the moving sheet, and is rolled under as the sheet advances. Scoriaceous rock is thus transferred from the surface to the base of a lava stream. Where sheet has succeeded sheet, each formed by an outpouring of molten rock, it is frequently difficult to say just where the junction plane separating them is located, for the reason that the rough, scoriaceous surface of the lower sheet is involved and embedded in similar material, which was poured out over it.

The basal portions of lava sheets, especially when they rest upon soft deposits like clay, are sometimes smooth, and have a dense outer rind with a glassy structure, due to rapid cooling. An instance of this nature observed at Spokane is described on page 53.

The cavities in scoriaceous lava frequently become filled with mineral matter, and on breaking open the rock that has undergone this change kernel-like grains are found instead of cavities. The mineral matter in such instances, most frequently some form of quartz, has been deposited from solution by percolating water since the rock hardened. Rocks containing cavities which have been filled in this way are termed *amygdaloids*, from the resemblance of the kernels to almonds. The kernels or amygdules may be of any shape, however, and not infrequently in the Columbia lava are very irregular. In some of the layers of the lava, as was observed especially in the canyon of the Grande Ronde, the cavities are not completely filled, but each one has a thin lining of quartz. As the rocks weather the small hollow kernels are liberated and occur scattered through the soil.

Larger cavities in the lava at times become filled with a form of silica known as chalcedony, which has a yellow color and looks like bright yellow resin. When this mineral presents bands or layers of different color, it is known as onyx. The presence of this mineral in the Columbia lava has led to crude mining at a few localities with the hope of discovering beds of onyx, but thus far little if any material of commercial value has been found.

Another form of silica, known as opal, also occurs as amygdules in the Columbia lava, and very beautiful stones having bright colors have been obtained. These stones are of the variety known as harlequin opals, and are frequently of great brilliancy and in every way of excellent quality. Opal mining has been carried on in a small way at Moscow and a few other localities in Idaho, and the conditions seem favorable for continuing this industry. Common opal, of a milky-white color and without the gorgeous play of colors that makes the harlequin opal one of the most beautiful of gems, occurs at very many horizons, and so long as we do not know the precise conditions that

of lava flows. In dealing with the artesian problem it is necessary to consider various conditions besides the character of the lava, and this discussion will therefore be postponed to a later portion of this report.

CLAY AND GRAVEL INTERSTRATIFIED WITH THE COLUMBIA LAVA.

Yakima Valley.—In the region occupied by the Columbia lava in central Washington, to the west of Columbia River, and described in a previous report,[1] there are several widely spread sheets of clay, gravel, sand, etc., of sedimentary origin, interleaved with the lava sheets. The brief account given in the report referred to, of the relation of the lava to these interbedded deposits, is as follows:

> Near the upper surface of the Columbia lava, in the Yakima region, there is a thin layer of clay formed as a sediment in a Tertiary lake, and subsequently covered by a lava flow a hundred feet thick. Above this bed of basalt and resting evenly on its surface are gravels and fine, evenly bedded lacustral sediments, having a thickness of 125 feet; then comes an interstratified sheet of columnar basalt, from 40 to 100 feet thick, which may be traced from the hills about Ellensburg eastward to Columbia River and which appears again in the eastern portion of Saddle Mountain. Above this layer there are other lacustral deposits, belonging to the John Day system. Besides the widely spread interstratified sheets of basalt there are others more local and less well known; one of these was penetrated while drilling the artesian wells in Moxee Valley.

Southeastern Washington.—The examination made of the geology of southeastern Washington failed to show that deposits of aqueous origin, interstratified with the Columbia lava, are there as numerous as in the region mentioned above, to the west of the Columbia. This is an important matter, as it has a direct bearing on the question of artesian water supply. The localities where sedimentary beds occur interleaved with the basalt to the east of the Columbia are mostly near the eastern boundary of the basaltic plateau, in Spokane, Whitman, and Asotin counties.

A possible reason for the fact that a greater number of sedimentary beds interstratified with the basalt have been recognized in the region west of the Columbia than in the country having a similar geological history to the east of that river may be that in the western area the lavas and interbedded deposits have been disturbed from their original horizontal position and the vast blocks bounded by faults have been upraised so as to expose the edges of the strata composing them and to allow the weathering out of the soft beds, in part, in such a manner as to reveal their presence in the topography. In southeastern Washington the rocks are, for the most part, still horizontal, and the only sections exposed to view are in canyon walls. Unless the escarpments are unusually steep, the soft beds are apt to be concealed by talus slopes and soil, and their presence masked. A more detailed study of

[1] Bull. U. S. Geol. Survey No. 108, 1893, p. 22.

the geology of this region will perhaps reveal a greater number of sedimentary beds in the basaltic area than is at present known.

Walla Walla Valley.—At a locality on the south side of Walla Walla Valley, about midway between Walla Walla and Wallula, the upper portion of a bed of fine clay beneath basalt is open to view for a short distance. The thickness of this bed that is exposed to view is only about 4 feet, but its total thickness is unknown.

Asotin country.—Near Asotin, on each side of Asotin Creek and less clearly exposed in the neighboring portion of Snake River Canyon, there are two horizons, one about 360 and the other approximately 700 feet above the town of Asotin, at which light-colored, evenly stratified clays appear between thick layers of basalt. The lower bed of clay is in the neighborhood of 40 feet thick; the upper one is certainly much thicker, but has not been measured. These sheets of clay are probably of wide extent, but owing to the manner in which comparatively thin, soft layers in a great series of hard beds became concealed at their outcrops in canyon walls by débris and soil, their presence was not clearly recognized in the bluffs and precipices bordering Snake River.

Palouse country.—At Pullman the upper portion of a bed of heavy clay is exposed near the bottom of the steep-sided valley in which the business portion of the town is located. This bed, as shown in railroad cuts northwest from the town, and in part by well borings, is about 30 feet thick. Its upper portion, to the depth of from 4 to 6 feet, has been baked and hardened by the heat of the lava that flowed over it, and is frequently dark, almost black, in color. At the immediate junction the clay is so much altered that it is difficult in small exposures to distinguish it from the overlying basalt, especially when the latter is somewhat weathered and disintegrated. Numerous vertical joints in the altered clay also increase its resemblance to igneous rock. This hardened surface portion of the stratum of clay, when traced downward, changes to unaltered clay, which in some places is yellow, light colored, and sandy. The thickness of basalt above this stratum is not less than 150 or 200 feet.

About 60 feet below the clay layer just described there is a second bed of sedimentary origin, composed of light-colored, unconsolidated quartz-sand and gravel, containing an abundance of mica. The rock intervening between these two sedimentary layers is compact, black basalt. The stratum of sand and gravel referred to has been revealed in drilling artesian wells, and has been penetrated to the depth of a few feet, but its thickness is unknown. It is abundantly water bearing.

The upper sedimentary bed at Pullman is plainly the sediment of a lake that existed on the basaltic plateau during an interval between the outpourings of lava. The layer of gravel and sand, 60 feet below, is of the nature of a stream deposit, or possibly the shore formation

of a lake, and was derived mainly from the disintegration of the granitic hills bordering the basaltic plateau on the east. The distance from Pullman to the nearest granitic hills to the eastward that rise above the present surface of the plateau is only about 8 miles.

In drilling a well at Palouse, 12 miles northeast of Pullman, a water-bearing stratum of sand and gravel similar to that beneath Pullman was reached at a depth of about 100 feet below the surface. Palouse is, by aneroid measurements, 100 feet higher than Pullman, hence the water-bearing beds at these two localities are not the same. The gravels and sands at a depth of 100 feet at Palouse may represent the clay layers exposed in the streets of Pullman.

At Garfield a drilled well was put down to a depth of about 300 feet, but so far as I can learn no sedimentary deposits were reached. Three miles northeast of Garfield, however, on the farm of James Walters, a drilled well, 113 feet deep, passed through basalt for 65 feet from the surface and entered clay 14 to 15 feet deep, beneath which water-bearing sand was reached, from which water rose and overflowed at the surface.

In a north-and-south belt of country in general, some 8 or 10 miles wide, beginning about 4 miles south of Pullman and extending to beyond Rosalia, there are reported to be 40 or 50 wells that penetrate water-bearing strata interbedded with the sheets of basalt. The records of these wells are not all available, and in general the level of the ground at the surface where they are located is not accurately known. For these reasons it is impracticable at this time to construct a section of the rocks of the region.

A mile south of Palouse, and again about a mile west of Garfield, deposits of sandy clay and of pure white kaolin have been opened. At the first-mentioned locality the clays are used for making fire brick and pottery. These deposits are evenly stratified and evidently of lacustral origin, but the depth of soil about them renders it uncertain whether or not they are interbedded with basalt. There is little doubt, however, that they represent lake deposits that were covered with basaltic overflows, and that they were revealed at a later period by the erosion of stream channels. These deposits are similar to certain clays in Spokane, described later, that are covered with thick sheets of basalt; a fact which lends support to the hypothesis just stated.

The conditions described in a general way as existing from Pullman northward to Rosalia are probably continued northward to Spokane, but this tract of country was not examined. At Spokane I spent two days in making a hasty study of the exceedingly interesting geological features there well displayed.

Spokane.—Excavations made in the southern part of the city of Spokane have revealed important beds of coarse gravel and sandy clay with a thick sheet of Columbia lava above. Similar beds of basalt occur beneath the sedimentary layer, as is shown by other excava-

ons, as well as along the adjacent portions of Spokane River. The ost instructive of the excavations referred to is near the south end f Barnard street, now graded, where an electric-car line leaves the reet and curves abruptly eastward. This cut is in general about 20 et deep and approximately 150 feet long. For about 130 feet from arnard street thin-bedded sandy clays with much mica and containg fossil leaves are exposed. A thickness of 10 or 12 feet of this eposit is in sight, but its bottom is nowhere revealed.

Resting in an irregular manner on the micaceous clays are coarse, ncemented gravels and water-worn bowlders. Above the gravel lies e covering of basalt, which, as shown in neighboring cliffs, is not ss than 50 or 75 feet thick. An interesting feature of the basal poron of the covering sheet of basalt is the irregularity of its lower surce. The bottom of the basaltic sheet has rounded, smooth-surfaced rotuberances or corrugations, between which the gravel and bowlers, together with detached fragments of the micaceous clay, freuently 12 to 16 inches in diameter, extend upward for 8 or 10 feet. ragments of the micaceous clay in contact with the basalt show eviences, in their compactness and reddish color, of the effect of the eat of the lava which came in contact with them.

A rough sketch of the exposure described above, as seen in the orth wall of the cut, is here reproduced from my note-book:

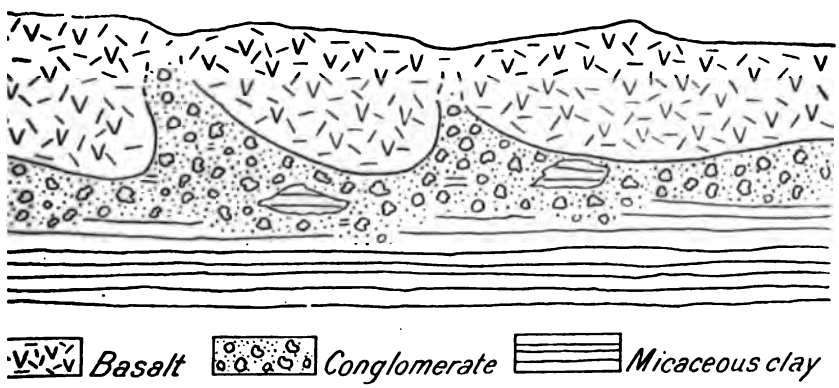


FIG. 1.—Section of lava flow and lake beds at Spokane.

The surface of the basalt is not only smooth, but when broken was und to be exceedingly dense and hard. The rock to a depth of about inches has a vitreous luster and is almost a glass. Evidently this rface layer was cooled quickly.

The explanation of the peculiar relation of the basalt to the gravel d clays beneath it seems to be that the lava in a molten condition wed over the deposits on which it rests in a direction from left to ght, as shown in the above section. The loose deposits were disrbed and forced along in front of the flowing lava until the resistance came sufficient to check its progress, and at the same time the lava

became cool and rigid. Still liquid lava broke out from the face of the arrested flow and advanced beyond the previously cooled border, overflowed the accumulation of stones and fragments of the micaceous clay, and again forced up a ridge of the loose material. This process was repeated several times in the portion of the flow exposed, and accounts for the marked inequalities in the under surface of the basaltic sheet and the manner in which confused masses of gravel and detached fragments of clay extend upward into the basalt.

The explanation just suggested is in harmony with the manner in which lava flows are known to advance. In describing the flow of lava streams on the Island of Hawaii, Dutton says:[1]

> After running some miles it [the molten lava] reaches more level ground, where it spreads out in great lakes or fields. It also cools on the surface, which gradually freezes over. But it is still hot within, and beneath its hardened covering the liquid rivers are still running, and at the edges and along the front of the great sheet the liquid lava constantly breaks forth, pushing out fiery rivulets in advance and laterally.

The lava that covers the lake beds and gravel deposit in Spokane appears to have advanced into a shallow lake, the bottom of which was disturbed and forced up in ridges. The contact of the lava with the water caused it to congeal rapidly and to form a glassy outer layer.

Near Spokane there are deposits of kaolin, similar to that already mentioned as occurring near Palouse, but remarkably fine and pure. I have not visited the pits from which this material is obtained, but from its character it appears to belong to the series of deposits under consideration.

Deposits of volcanic dust and lapilli.—On a previous page mention has been made of a layer of pure-white volcanic dust beneath a thick sheet of columnar basalt in Snake River Canyon, above the mouth of Alpowa Creek. This deposit owes its origin to a violent volcanic eruption, the location of which is unknown, that blew great quantities of exceedingly fine dust high in the air. The dust was carried by the wind to great distances and spread as a sheet over the land. This eruption occurred during one of the later intervals in the outpouring of the Columbia lava and the deposit was buried by the next succeeding lava overflow. The stratigraphic relation of this bed of volcanic dust to the overflow of Columbia lava is similar to that of the interbedded lacustral clays and stream-deposited sand.

In excavating for an irrigating canal on the side of Snake River Canyon at Pigeon Rock, below Asotin, a bed of coarse, yellowish, fragmental volcanic material over 10 feet in thickness was exposed. This deposit has compact lava sheets above and below, and owes its origin to the deposition of fragments of volcanic rock, frequently

[1] C. E. Dutton, The Hawaiian Islands and People; a lecture delivered at the United States National Museum, 1884, p. 13.

inches in diameter, which were blown out by a volcano, or perhaps formed by molten lava coming in contact with water. The fragments composing this lapilli sheet are of the same character as the dense, vitreous layers already described as forming the under surface of a lava sheet at Spokane. These lapilli deposits, unlike the sheet of white volcanic dust mentioned above, belong to the eruptions that poured out the Columbia lava, and are not, therefore, of distant origin.

Résumé.—Interleaved with the sheets of basalt forming the series named the Columbia lava, there are, as just shown, sheets of lacustral clay and of stream-borne gravel and sand, and layers of volcanic dust and of volcanic fragments termed lapilli. The lake beds appear to occur mostly near the border of the lava-covered country, for the reason that, in eastern Washington at least, the lava sheets flowed toward the mountains, and on congealing dammed their draining streams. The surface of the cooled and hardened lava flows must have had a slight slope in the direction of flow. The supposed absence of lake beds over the more central portions of the lava may be due to lack of information, but seems to be a necessary result of the manner in which the lava sheets encroached on the mountains and blocked their draining streams. Shallow lakes were probably formed on the surfaces of the cooled lava sheets far from the mountains, but being at a distance from highlands that could furnish débris, they would not be deeply filled, and records of their existence would not be conspicuous.

The layers of volcanic dust, from the nature of their origin, should be widely spread, but up to the present time they have been observed in but few localities. Sheets of lapilli have been noted in the Big Bend country and near Asotin, but whether they are extensive or not remains to be determined. These various deposits found between the layers of Columbia lava at different horizons not only record interesting episodes in the history of the basaltic inundations, but, as will be shown later, have a direct and important bearing on the question of artesian water supply.

JOHN DAY SYSTEM.

In my report of a reconnoissance in central Washington, already cited, certain lacustral deposits are described which rest on the surface of the latest extensive lava flow of the Columbia system. This series of lake sediments consists principally of stratified clays, with thick strata of white volcanic dust, and in certain localities contains beds of coarse conglomerate. It is termed the John Day system, for the reason that it is thought to be an extension of a similar formation which occurs in John Day Valley, Oregon. The connection between these two areas has not been actually traced, however, and the correlation just suggested must be considered as provisional.

Beds of light-colored clay and of white volcanic dust, which have been referred to the John Day system, occur at the White Bluffs

of the Columbia, 30 miles above Pasco, and are also well exposed in Naches Valley and near Ellensburg, in Yakima County. At these localities the impressions of the leaves of a large variety of plants and the bones of extinct animals have been obtained. The plant remains indicate that the shores of the ancient lake into which they were blown or washed by tributary streams were clothed in a varied and beautiful flora, resembling, in a general way at least, the vegetation of the South Atlantic and Gulf States at the present day. In the ancient forest and about the shores of the old lake, now known as Lake John Day, a veritable menagerie of strange and in part gigantic beasts found a congenial home.

From the White Bluffs of the Columbia southward to the region described in this report there are no barriers, but the surface of the country rises gradually from the broad valley of the Columbia to the basaltic plateau of northeastern Washington. From studies made along the Columbia in 1892, I was led to the conclusion that Lake John Day extended far eastward and covered nearly all of southeastern Washington, even to the base of the Blue Mountains. This view is now known to have been in part erroneous. The sediments of Lake John Day are but poorly exposed to the east of Pasco and Wallula, and their extent in that direction, although not clearly shown, is certainly far short of the Blue Mountains and of the Idaho boundary. They cover the Eureka flats, however, as is shown by a well 198 feet deep at Eureka Junction, which is all in strata similar to those exposed in the White Bluffs of the Columbia, but does not reach the bottom of the formation. Fossil leaves were found in the rock removed in digging the well similar to those obtained from other portions of the John Day system. With the exception of the rocks found at Eureka Junction, no exposures of the Lake John Day system have been recognized in the region treated in this report. The sediment of the old lake does not occur above the Columbia lava in the vicinity of Walla Walla, Dayton, and Starbuck, and its eastern shore must have been to the west of these localities.

The lacustral deposits described in the preceding section as being interbedded with the Columbia lava are of about the same age as the John Day system and were accumulated under similar conditions. They should perhaps be included in the same system, but further study is necessary before a conclusion in this connection can be reached.

RIVER TERRACES.

In describing the canyons of Snake, Spokane, and other rivers in a preceding section mention was made of gravel terraces which occur in them. Little remains to be said in reference to these terraces, except to indicate their place in the geological history of the region where they occur. That they are younger than the Columbia lava and the lake beds, either interleaved with them or resting on their

surface, is shown by the fact that they occur in canyons that have been excavated in these formations. The canyon of Snake River, for example, was cut to its present depth before the gravels forming the great banks which occur at certain localities within it were deposited. The canyon was filled in with gravel from side to side to the depth of 360 feet and then reexcavated. Since the river cut through this gravel deposit, removing by far the greater portion of it, but little if any progress has been made in deepening its bed in the solid rock below. Evidently the gravel deposit belongs to a comparatively modern episode in the history of the great gorge. Several considerations lead to the conclusion that the canyon was excavated to its present depth in late Tertiary times, and was filled in with gravel during the Glacial period. If this inference is correct, the amount of excavation done since the Glacial period is trifling in comparison with the work performed by the river previous to that period.

SOILS.

ORIGIN OF SOILS.

Soils in general consist of more or less thoroughly disintegrated and decomposed rock. The surface layer usually contains organic matter termed humus, derived from the partial decay or chemical alteration of organic matter, principally of vegetable origin.

In many regions the breaking down of the rock supplies more material for soil making than is removed by streams or blown away by the wind. Again, denudation may keep pace with disintegration and decay and all of the loosened soil material be removed, so as to leave bare rock surfaces. Much of the soil material removed from one area is redeposited in another area, and hence it is convenient to recognize two kinds of soils, classified in reference to whether they have been removed from their place of origin or not. These two general classes are *residual soils* and *transported soils*. Under each of these divisions many minor subdivisions, dependent on chemical or mechanical composition, have been recognized.

The residual soils are such as originate from the disintegration and decay of the rocks on which they rest. They are the residue left after a long process of weathering and leaching by percolating water, which has removed most of the more easily soluble constituents. Some movements in the soil cap probably always attend this change, but the residue remains practically on the area where it was formed. In recognition of this fact the term "sedentary soil" is sometimes used instead of the one here employed.

The transported soils consist of the products of rock disintegration and decay and of rock abrasion, which have been removed from the area where they were produced, usually through the agencies of streams, glaciers, or the winds, and redeposited. A familiar example

of soils of this class is furnished by the silts, sands, and clays forming the flood plains of streams.

In the region represented on the accompanying map not only are both transported and residual soils abundantly represented, but several varieties of each, dependent on mechanical and chemical differences, may be easily recognized.

SOILS OF THE VALLEYS AND CANYONS.

The soils in the valley bottoms in southeastern Washington, more especially in the smaller valleys and along the borders of the smaller streams, although belonging strictly to the transported soils, are frequently of the same character as the soils of the adjacent uplands, or plateau surface, and have been removed but short distances from their place of origin.

The bottom lands adjacent to Walla Walla River and the sand bars in Snake River Canyon, in the valley of Spokane River and elsewhere, are typical examples of transported soil. The mineral and rock fragments composing these soils are, in general, more varied in character than the grains in the residual soils, and have been brought to the localities where we now find them by stream transportation.

About Wallula and Pasco the country is covered over large areas with sand and dust. The surface coverings of this desert-like region represent another variety of transported soils, in which wind is the transporting agency.

The transported soils in the region under discussion may be easily recognized, particularly on account of their topographic relations and the heterogeneity of the rock fragments contained in them, and need not be considered further at this time.

SOIL OF THE WHEAT LANDS.

The deep, rich soil covering the broad basaltic plateau of southeastern Washington and extending widely into Oregon and southwestern Idaho is a residual soil formed by the disintegration and decay of the lava rocks on which it rests. This is the justly celebrated soil of the wheat lands.

To the residual material left by the breaking down and partial solution of the lava have been added minor quantities of terrestrial and volcanic matter; and cosmic dust, or the particles derived from meteors which come to the earth from space, should also be mentioned in this connection.

The plateau is covered nearly everywhere with a rich soil that is unusually fine and porous and free from stones and obstructions of every kind. To the plow it offers scarcely more resistance than so much meal. The surfaces of plowed fields are of a dark-brown, almost black color, due to organic matter or humus. This humus is in part an inheritance from the centuries during which the rolling

WHEAT LANDS NEAR MOSCOW, IDAHO.

plands were covered with bunch grass, and in part has been derived rom the decay of the stubble of wheat fields. At a depth usually of to 8 feet below the surface the dark color fades away and the subil, equally fine and homogeneous, and having the same mineral mposition, but of a light and usually a yellowish color, is revealed. he subsoil varies in depth with the relief of the surface and with ie topography of the underlying hard-rock surface, but is nearly lways deep. Systematic measurements are wanting, but judging rom the thickness of superficial material revealed in wells, railroad uts, and other excavations, the subsoil has an average depth of etween 50 and 80 feet. Many natural and artificial sections that ere examined revealed a depth of 40 to 50 feet, usually without xposing the underlying rock.

In all sections of the subsoil it appears as a fine, homogeneous, nstratified formation, having a uniform light-yellow color.[1] There re frequently indications of vertical joints, or narrow dividing planes, ut whether these have developed in the soil, or are possibly an inherance from the basalt from which it was derived, is an open question. raversing the subsoil from top to bottom are innumerable minute nd almost capillary tubes. These are, in a general way, vertical, ut they are curved and otherwise irregular. A single tube can selom be traced for more than 3 or 4 inches, and their extremities are eldom discoverable, but scarcely a cubic inch of the subsoil is without a number of them. In the humus layer, however, they are absent.

Geologists will, I think, at once recognize, from the above description, the close similarity of this deep subsoil to loess deposits. This esemblance includes the color, the dust-like fineness of the material, he absence of stratification, and the presence of minute and nearly

[1] A characteristic sample of the soil of the wheat lands has been submitted to a mechanical alysis made by Milton Whitney, chief of the division of soils in the United States Department Agriculture, with the following results:

Mechanical analysis of soil from near Pullman, Washington.

Diameter (in millimeters).	Conventional name.	Per ct.
2 to 1	Fine gravel	0.00
1 to .5	Coarse sand	0.04
.5 to .25	Medium sand	0.16
.25 to .1	Fine sand	1.31
.1 to .05	Very fine sand	53.72
.05 to .01	Silt	26.29
.01 to .005	Fine silt	2.97
.005 to .0001	Clay	8.58
Total mineral matter		93.07
Loss at 110° C		2.45
Loss on ignition		5.20
Total		100.72

vertical tubes. These features also characterize the adobe deposits of arid regions.[1]

The close similarity between the soils of the basaltic plateau and the loess of China, which is supposed by many to consist of wind-deposited dust, has led some careful observers to conclude that the soil of eastern Washington is really a deposit of dust that has been drifted from a distance by the prevailing winds. The minute tubes referred to are considered under this explanation to be due to the rootlets or stems of grasses about which the dust was deposited, the plants continuing to grow as the dust accumulated. There are several objections to this hypothesis, however, as will be shown below.

In numerous sections the surface of the basalt beneath the subsoil has been examined and always found to be deeply decayed. A gradual change can be traced from hard, black basalt, which reveals no signs of weathering, upward through yellow and partially disintegrated portions of the same layer, to rock fragments that are soft and much decayed, and from this, again, to fine soil containing recognizable rock fragments, and finally to the exceedingly fine porous subsoil. Scores of localities where this gradual change is exhibited have been examined, and the number might easily be increased to hundreds.

Chemical analyses of a large number of soils from various localities in Washington and Idaho, including samples from the basaltic plateau, have been made by the chemists of the agricultural experiment stations at Pullman and Moscow.[2] These analyses show that the chemical composition of the soil on the basaltic plateau is such as might be expected to result from the weathering of the solid rocks beneath.

The disintegration of rocks is usually accomplished in part by changes of temperature and by the expansion of water held in crevices and absorbed by pores and capillary passages, on freezing, and in part by the solvent action of percolating waters and, as recently determined by G. P. Merrill, the expansion of minerals in changing to a hydrated condition. Changes of temperature which cause the minerals composing a rock to expand and contract unequally and the freezing of absorbed water are important agencies tending to fracture rocks which are exposed to the air or but thinly covered with soil. A depth of a few feet of soil, however, checks this action, so that the deep decay so frequently to be observed can be safely ascribed to the chemical action of percolating water. The process is hastened by the presence in the water of organic acids, derived principally from the humus of the surface soil. The disintegration and decay of rocks that are sheltered from changes of temperature is brought about to a

[1] I. C. Russell, Subaerial deposits of the arid region of the United States: Geol. Mag. (London), Vol. VI, 1889, pp. 289–295, 342–350.

[2] Washington State Agricultural College and School of Science, Experiment Station, Pullman, Washington, Bulletin 13, 1894, by Elton Fulmer and C C Fletcher. University of Idaho Agricultural Experiment Station, Bulletin 9, 1894, by C. W. McCurdy.

VIEW OF PULLMAN FROM THE AGRICULTURAL COLLEGE LOOKING NORTHWEST

onsiderable extent by the removal of some of their constituents in olution. This process allows the grains and crystals which remain naltered or are but moderately changed to fall apart. We should xpect, therefore, that residual soils would contain less of soluble onstituents than the parent rock, and consequently a higher per-entage of the more insoluble constituents.

Samples of the basalt and of the subsoil and soil resting on it were ollected by the writer and submitted to George P. Merrill, curator f the department of geology in the United States National Museum, or special study. Chemical analyses of three of the samples are resented below. The analysis of basalt is of a fresh and unaltered ample, being in fact a part of the specimen of which the mineral-gical constituents are given on page 44; the subsoil is from a depth f 30 feet in a railroad cut near Dayton; the surface soil was taken rom a depth of about 2 feet in a wheat field near the same locality.

Analyses of basalt, soil, and subsoil from near Dayton.

[Analyst, George P. Merrill.]

Constituents.	Basalt.	Surface soil.	Subsoil.
Silica, SiO_2	47.85	63.58	65.89
Alumina, Al_2O_3 Iron oxide, Fe_2O_3	34.88	22.36	22.19
Lime, CaO	8.27	2.76	2.36
Magnesia, MgO	4.43	1.82	1.85
Potash, K_2O	1.33	2.27	2.36
Soda, Na_2O	2.55	2.02	2.08
Loss on ignition (principally organic matter)	0.95	4.37	2.60
	99.26	99.18	99.33

Merrill states:

All of the material analyzed was first dried at 100° C. The analyses are not as tailed as I would like to make them, but are all that the limited time permits. erhaps the most striking fact in the analyses is the similarity in composition tween the surface soil and that from a depth of 30 feet; almost the only essen-al difference being, apparently, the larger percentage of volatile matter of the rface soil. Not having as yet separated the iron and alumina, I am unable to count for the apparent loss of these constituents shown. From previous analy-s I am led to suspect that the iron oxides have been very largely removed. I n unable as yet to account for the apparent increase in potash in the decomposed aterials. It is possible, though hardly probable, that this is due to errors in alysis.

In reference to the apparent increase in potash in the decomposed aterial, I wish to state that there is no reason for supposing that

alkaline or other fertilizers have ever been applied. Possibly the stubble of the wheat fields may have been burned, but this would only return to the surface soil a part of the mineral constituents derived from it in the growth of the grain.

The close similarity between the composition of the subsoils, given above, and of the rock beneath it, is striking. All of the constituents of the rock except the silica and alumina are classed among the more soluble of the substances present in the earth's crust. The readiness with which they may be removed from rock by the process of solution is influenced, of course, by the manner in which they are combined, but the study of the products of rock decay has shown that lime, potash, magnesia, soda, etc., are much more readily removed than silica and alumina. The analyses given above indicate no departure from this rule except in the case of the potash. The soil analyses show that there has been a loss in all of the constituents of the original rock except silica, alumina (?), and potash. The increase in the percentage of potash, as remarked above, is surprising, and as yet unaccounted for. Organic matter and water have been added. The former may reasonably be supposed to have been derived from humus, while the latter indicates that some of the minerals have taken up water and changed to what is termed a hydrated condition. If we omit these added constituents and recalculate the analysis, it will appear that the percentage of silica in the soil is 67 per cent, a decided increase over the similar constituent in the rock, and that each of the other constituents is proportionately increased.

Several analyses of soils from the basaltic plateau, given in the bulletins of the agricultural experiment stations mentioned above, show that the one just quoted is typical and represents about the average composition of the soils of the wheat lands. The analysis of basalt also is of a normal sample of that rock.

The results of a chemical study of the soils and of the basalt are, then, in harmony with what is revealed on comparing the mineralogical composition of the basalt with that of the soils, and sustain the conclusion that the soil has been derived from the rock which it overlies, and also that the disintegration is due, in part at least, to the solution of the more soluble constituents of the parent rock. The loss in bulk, due to the removal of portions of the more soluble constituents, is counteracted to a considerable extent, however, by the hydration of some of the minerals and by the addition of organic matter. This is an interesting fact, as it indicates that there has been at most but a moderate lowering of the surface of the plateau by the removal of matter in solution. Indeed, as the soil is far more open and porous than the parent rock, there has been a tendency toward an actual increase in the elevation of the surface of the plateau. How much this rise of the surface level has been counteracted by stream and wind erosion

remains to be determined. The fact that water percolating through soil leads to the removal in solution of some of its constituents is well known, and has been fully recognized in the case of the soils of Washington by Professors Fulmer and Fletcher, of the Washington State Agricultural College, as is shown in the following quotation:[1]

> Results of a large number of analyses have shown almost conclusively that soils in a reigon of abundant rainfall contain less lime than soils in arid regions; providing, of course, that neither are underlaid by or in the vicinity of limestone formations. [It will be shown below that this exception need not necessarily be made.] This fact is well verified in the case of our soils east and west of the Cascade Mountains, the average lime constituent of the former being three times that of the latter. This is specially significant in view of the fact that nearly all the soils of eastern Washington are derived from black basaltic rock.
>
> With the samples analyzed so far, it seems almost as if the lime percentages are inversely proportioned to the amount of annual rainfall.
>
> For example, we find the following relations:

Lime percentages.	Annual rainfall.
1.2127 0.9790	About 8 inches.
1.7580 1.0814 1.1800 0.7810 0.9300	20 to 22 inches.
0.6550 0.7690	24 inches.
0.3625 0.4315 0.1303	48 inches.
0.1090 0.0829	76 inches.

> It will be interesting to note whether future analyses will reveal this same relation between the rainfall and the lime content of our soils.

The origin of soils from the disintegration and chemical change of rocks is well known, and there is nothing novel, so far as general principles are concerned, in the interesting statements just quoted in reference to the relation of the chemical composition of soils to climatic conditions.[2]

One of the most remarkable instances of the decrease in the soluble constituents of a rock when it passes into soil, given in the papers just referred to, occurs in the limestone region of the western part of Virginia, which, as is known to me from personal observation, is representative of a vast area in the South Atlantic States. The limestone referred to in general yields on decomposing about 1 per cent of insol-

[1] Washington State Agricultural College and School of Science, Experiment Station, Bulletin 12, pp. 39-40.

[2] The processes of rock disintegration and decay, the formation of soils, their variation under diverse climatic conditions, etc., have been discussed by the present writer in Bulletin No. 52 of the United States Geological Survey. A highly instructive analysis of the same phenomena, by George P. Merrill, of the United States National Museum, may be found in volume 4 of the Journal of Geology, published at the University of Chicago. References to many other papers on the same subject are given in these essays. See, also, A Treatise on Rocks, Rock-weathering, and Soils, by George P. Merrill, The Macmillan Company, 1897.

uble residue which is available for making soil. Analyses illustrating this are here inserted:[1]

Analysis of Trenton limestone and of the residue left by its decay.

[Analyst, R. B. Riggs.]

Constituents.	Unaltered limestone.	Residual clay.
Silica, SiO_2	0.44	43.07
Alumina, Al_2O_3	0.42	25.07
Iron oxide, Fe_2O_3		15.16
Lime, CaO	54.77	0.63
Magnesia, MgO	Trace	0.03
Potash, K_2O	Not determined	2.50
Soda, Na_2O	Not determined	1.20
Carbonic acid, CO_2	42.72	0.00
Water, H_2O	1.08	12.98
Total	99.43	100.64

The residual soil left by the nearly complete solution of limestone at the locality from which the sample analyzed was taken is a tenacious reddish clay, and is so poor in lime that calcined limestone is found to be a desirable fertilizer.

The change from basalt to residual soil on the surface of the great plateau of southeastern Washington is accompanied by less change in chemical composition than in the case cited of the formation of soil from the weathering of limestone, for the reason that so large a proportion of the basalt is composed of silica.

It seems, therefore, both from a comparison of the mineralogical character of the fragments composing the soil with the nature of the minerals composing the basalt, and from a study of the chemical composition of the unaltered rock and of the soil, that the subsoil is the result of the disintegration and decay of the country rock. The surface soil is of the same character as the subsoil, except that organic and atmospheric matter and volcanic and probably cosmic dust have been added.

An unexplained fact under this hypothesis is the presence in the subsoil of the minute and nearly vertical tubes previously described.

TOPOGRAPHY OF THE WHEAT LANDS.

The widely different ideas of the topography of southeastern Washington that one might obtain from traveling through the canyons and from a journey over the plateau surface have already been referred to. It is to the peculiar topography of much of the surface of the

[1] Bull. U. S. Geol. Survey No. 52, 1889, p. 24.

plateau where practically unaffected by the deep dissection accomplished by the larger streams that attention is here directed.

The surface of the plateau in some regions is nearly as level and featureless as the prairies of Illinois, while in other portions it is diversified by hills and valleys, and in its native state, when covered with bunch grass, was a rolling prairie. South of Snake River, especially on the portions of the plateau which remain between the various branches of Touchet, Alpowa, and Asotin creeks, the flat plateau-prairie lands are well displayed. North of Snake River, in the Palouse country, the rolling or hilly prairie predominates over extensive regions.

There is a certain relation between the smoothness or roughness of the surface of the plateau and the arrangement of the streams, but I doubt if this is the sole reason for the contrast between the smooth surfaces of the fragments of the plateau between the deep canyons south of Snake River and that of the hill plains to the north. Where the streams flow across the plateau they have excavated deep canyons, with comparatively few lateral branches. The rain falling on the deep soil of the plateau is absorbed and percolated away. It is thus robbed of its power to erode. Under these conditions surface channels, like those so common in many regions having a clayey soil, are not formed. At a distance from master streams, where the subdrainage was less perfect, the soil seems to have become saturated, and rills and rivulets appeared on the surface and flowed to brooks, and these to larger streams. The soil in such regions has been carved into hills and ridges, with hollows and shallow valleys between. The hills and valleys of the rolling prairie region, as will be shown below, were still further modified by the wind.

When one gains a comprehensive view of the surface of the plateau—as, for example, from the borders of the Blue Mountain uplift or from the sharp summit of Steptoe Butte—it is seen that the controlling features in the topography of the surrounding country are due to stream erosion. A map of the plateau would show that where the broad, level, plain-like features predominate, the land is incompletely drained. There are no rill and brook channels ready to carry off the rain water, should it fall in sufficient abundance to form surface streams. In the hilly portion of the plateau, however, as in the Palouse country, there are countless small valleys and depressions that join large channels and everywhere favor the running off of surface water. The portions of the plateau's surface that have not been etched by stream erosion are, in the language of geographers, young land areas, while the roughened surface of the rolling prairies furnishes examples of youthful topography, or, in this instance, of arrested development in an early stage of growth.

These conclusions may not seem well founded to those who are aware that the portions of the plateau between the deeply cut canyons are

without surface streams. Even where the plateau surface is hilly and the numerous minor valleys and depressions favor complete drainage, there are not only no streams at any time during the year, but no stream channels in the valley bottoms. There was formerly a time, however, when precipitation was more abundant than now, and the land in what is now the rolling prairie was sculptured by a multitude of rills and brooks.

The hilly prairie is characteristically developed in eastern Washington, north of Snake River, and probably extends to Spokane River. The most typical portion, so far as I can judge from personal observation, is in the region drained by Palouse River. The towns of Pullman and Garfield are surrounded by the characteristic hills here referred to, and from Kamiack and Steptoe buttes one can look down on tens of thousands of acres of hilly and undulating wheat lands, which in a state of nature formed a vast, hilly prairie.

In this region hills with smooth, even slopes and rounded tops and crests, rising in general from 20 to 80 feet above the adjacent depressions, occur in thousands. Many of the hills rise to one general level, but none reach above it. The fact that the roughened surface of the plateau is a broad plain is always apparent in a general view.

One feature of the hills which especially attracts attention is that they are usually steep on the northeast side and slope gently toward the southwest. The steeper sides frequently have a slope of 20° with a horizontal plane, and in many instances are slightly concave when seen in profile, while the more gently sloping sides descend at angles measuring 5° to 8°, and are frequently gently convex. These features may be recognized in the photographs of characteristic portions of the hilly plateau forming the accompanying plates.

In many instances the extremities of ridges which present a steep slope to the northeast terminate at each end in tapering prolongations extending northeastward, which curve slightly toward each other and partially inclose a hollow. Many of these amphitheater-like inclosures may be seen in the northeast sides of the hills about Pullman and Garfield.

From what has been stated, the fact will be recognized, I think, that many of the hills of the plateau are similar in form to the hills of drifted sand termed "dunes."

The dune-like shape of many of the hills about Pullman was first pointed out to me by President E. A. Bryan and Prof. C. V. Piper, of the Washington State Agricultural College and School of Science. These gentlemen also stated that the prevailing winds of that section of the country are from the southwest. The hypothesis was thus suggested that the soil of the plateau, of which even the highest hills are composed, has been blown by the prevailing winds and piled up in part in dune-like forms. The similarity in physical properties between the fine soil of the wheat lands and the equally fine, dust-like deposits

in China, termed loess, and believed by some geologists to be wind-borne deposits, as previously suggested, seemed also to give weight to the hypothesis that the hills under consideration are of eolian origin. The idea has been suggested that the soil of the wheat lands has been brought by the winds from a desert region to the southwest, but there is no extensive desert area in that direction, and besides, as we have already seen, the mineralogical and chemical composition of the soil and its transition into disintegrated rock and finally into solid basalt shows that it originated in the place where we now find it.

The prevailing and characteristic dune-like shapes of the hills is sufficient evidence, however, that their contours have been modified to some extent by wind action. As already stated, the main topographic features, even where the dune-like hills are best displayed, are such as are produced by erosion. The partially filled depressions between the hills have continuous slopes, which would furnish natural and unbroken channels of escape should the rainfall become sufficiently abundant to initiate surface drainage.

The best explanation I can offer of the origin of the hilly topography of the less deeply dissected portions of the basaltic plateau is that the principal changes in the relief of the surface of the originally flat and featureless plateau are due to stream erosion at a time when the precipitation was more copious than now, and that with a decrease in precipitation the forms of the hills, left in relief by the excavation of the valley, were modified by the prevailing winds. The fine soil was blown from the southwest sides of the hills, which trend northwest and southeast, and accumulated on their leeward slopes. But this action has not been carried far enough to obliterate or to greatly modify the topographic forms due to previous stream erosion. In no instance during a careful search extending over several days was I able to find a single valley or depression which was not connected with the present lines of drainage by valleys and dells that would admit of complete surface drainage in the case of a heavy rainfall. This evidently would not have been the case if the wind had been the controlling agency in modeling the relief of the plateau's surface.

The steep northeast slopes of the hills, as already mentioned, frequently have concave profiles. These curved slopes suggest the profiles of volcanic cones formed of fragments blown out of a volcano and falling about its sides. They are the reverse of the convex "weather curves" produced by the removal of the surface of an uplift in the process of weathering. The concave sides of the hills have such profiles as would be formed by material blown over their crests and accumulated on their lee sides; while their summits and southwest slopes present such profiles as normally result from weathering.

Excavations in the hills have in some instances shown a greater depth of fine, dust-like soil on the lee side of their crests than on the

windward side. In some cases a clayey subsoil is met with at a depth of a few feet on the southwest side, while on the opposite side a deep loess-like soil prevails. This has been noticed in the college farm at Pullman, as I have been informed by President Bryan, where clay interbedded with the Columbia lava has influenced the character of the soil. In railroad cuts deposits of fine, dust-like soil having a depth of 30 or 40 feet have been observed in several instances on the northeast side of hills; while in similar cuts on the southwest slopes of corresponding hills they would be less thick. Rock exposures are perhaps more numerous on the northern sides of canyons than on their southern sides, owing to the accumulation of soil in the lee of their southern walls, but I am not aware that there is a marked tendency in this direction.

I have thought, also, that a difference is observable between soil that has been moved and redeposited by wind and soil that remains in place, but the differences between the two are so slight and their junction so indefinite that no sharp line of division can usually be recognized.

It is possible that the vertical tubes described on a previous page occur only in the soil that has been moved by the wind. The tubes referred to are certainly abundant in the soil on the northwest slopes of hills, but whether they are absent in soil that has not been disturbed remains to be proven.

The valleys in the surface of the hilly plateau have characteristics, also, which are novel to one familiar only with a well-watered country. The great majority, and in fact nearly all, of the valleys of the plateau, except such as are traversed by streams flowing from the bordering mountains, are flat bottomed and without stream channels. These valleys are usually deeply filled with fine soil of the same character as that forming the adjacent hills. In cross section the valleys are level-floored, but in longitudinal section their even surfaces would show a gentle inclination toward the deeper valleys to which they lead, and in which there are streams flowing from the neighboring mountains.

As stated in connection with the description of other climatic features of eastern Washington, the precipitation is small, averaging about 16 inches annually. The deep, fine, porous soil absorbs the rain as it falls and the water formed from melting snow. It is to this fact that the possibility of raising wheat and other cereals on the broad plateau is due. All of the annual precipitation except what is returned to the atmosphere by direct evaporation, as when snow vanishes before a warm wind without melting, is not only absorbed by the soil, but is retained, to a great extent, near the surface. In excavations in excess of 15 or 20 feet on the plateau surface, I have been informed, dry soil is usually reached.

It is a striking fact, especially on the hilly portion of the plateau,

that even the steepest slopes, in many instances having an inclination of from 20° to 30°, are without rill marks. This is not because there is a mat of roots binding the soil together and thus preserving it from washing, for the surfaces of the plowed hillsides are smooth and unscarred by gullies. It is the custom generally throughout the wheat-growing region of eastern Washington, as already stated, to harvest but one crop in two years from a given area. The farmers have learned that by this method they can obtain about as much grain as if the land were sown and harvested each year. Inquiries as to the reasons that make this possible have not elicited satisfactory answers. The suggestion has occurred to me, however, that possibly the evaporation from a plowed field is so much less than from a field covered with growing grain that by plowing the land and leaving it unsown every other year a greater store of moisture is secured for the alternate years, when a crop is raised. This suggestion is in harmony with the well-known fact that the conditions which are favorable or unfavorable to agriculture on the basaltic plateau, with reference especially to moisture, are delicately balanced. When a slight increase over the average annual precipitation is experienced, an abundant harvest is secured; but if the precipitation—particularly the amount of snow—is small, the effect is seen in a diminished harvest. This statement must be qualified, however, since the amount of precipitation is not the only important climatic factor on which the success or failure of the harvests depends. In winter the snow, although perhaps abundant, is sometimes evaporated by warm, dry winds, without melting, and therefore fails to add to the store of moisture in the soil. Hot winds occur sometimes also in spring and early summer, and wither the young grain.

The semihumid character of the climate of eastern Washington, shown by the conditions limiting the cultivation of cereals, leads naturally to the consideration of the possibilities of irrigation and of artesian water supply.

IRRIGATION.[1]

Region south of Snake River.—To a person traveling through southeastern Washington, a truly astonishing feature of the country is the great quantity of water flowing from the Blue Mountains. I have already directed attention to the fact that on what has been termed the wheat-land plateau all of the water that reaches the soil is absorbed. The same is true among the Blue Mountains, which are in reality a more elevated plateau of the same general character that has been deeply dissected by stream erosion. This uplift furnishes a splendid example of mature drainage—that is, a drainage system which has cut down its principal channels approximately to the level

[1] For data on water supply and irrigation from Umatilla River, see Bull. No. 131, Report of Progress of the Division of Hydrography, United States Geological Survey, for 1893 and 1894, pp. 69–73.

of the master stream into which they discharge. The principal streams have developed innumerable lateral branches, so that the entire region is well drained. With the deepening of the stream channels there has been erosion of the interstream spaces, and instead of flat-topped tables, only sharp, serrate ridges remain. These stream channels are no older than the less well-developed channels on the lower plateau, but the advantage gained from the greater elevation of the land has given the flowing waters greater velocity and enabled them to progress with their appointed task more rapidly.

Rock disintegration and decay has kept pace with, and in recent times exceeded, denudation, and every depression and every shelf on the canyon walls is filled and covered with soil. This soil is of the same character as that of the wheat lands, except for the frequent occurrence of angular rock fragments in it. All portions of the intricate system of ridges composing the so-called mountains, except the actual cliffs and precipices, are thus soil covered.

Among the mountains, as on the hill slopes of the wheat lands, there is an absence of rill marks. Earth slopes having a descent of fully 45° are usually without rill marks or scars of any kind due to erosion. The few miniature water courses that do occur on such slopes are the result of the infrequent storms known as "cloudbursts." The water absorbed by the porous soil passes down into the jointed and frequently scoriaceous basalt below, and by slow percolation feeds perennial streams.

As already described in the section of this report devoted to drainage, and as shown on the accompanying map, there are many creeks, some of them having the volume of rivers, radiating in all directions from the Blue Mountains. Each of these streams flows throughout the year and carries a never-failing flood of clear, cold water down to the parched valleys below. Each of these streams, with the exception of the Grande Ronde, can be utilized to its full capacity for irrigation.

The Grande Ronde in all of its lower course, as already shown, flows through such a rugged canyon that scarcely any land can be economically irrigated by it. Here and there along the main river, however, and on its branches, are small areas, some of which may be watered from the river itself or by lateral streams. The productiveness of these areas makes them especially valuable for orchards and gardens. It is in these sheltered recesses that fruit, vegetables, tobacco, etc., may be raised, while the canyon sides and much of the plateau surface, some 3,000 feet above, is available for stock ranges. Toward the headwaters of the river broad areas of the plateau surface still remain and are clothed with forests. This land, when cleared, will produce wheat, but it is to be hoped that much of it will be retained in nearly its natural condition as a forest preserve.

The other streams referred to, which radiate from the Blue Moun-

tains of Washington and adjacent portions of Oregon, flow through canyons, but in most instances are bordered by narrow flood plains, elevated but a few feet above their channels, or by ancient terraces, as in the case especially of the Walla Walla and several of its branches. Of the streams under consideration, the ones least favorably circumstanced for irrigation purposes are Asotin and Alpowa creeks. But even these can be utilized, as is shown by the canal described below, which leads the water from Asotin Creek about the face of the bluffs forming Snake River Canyon and delivers it to irrigable lands opposite Lewiston. The Alpowa flows for a large part of its course in a narrow gorge, but near its mouth and along the adjacent portion of Snake River there are lands so situated that they can be irrigated.

In the absence of a topographic survey of the Blue Mountains and adjacent regions, it is not practicable to designate in a report of the character of the one here presented what lands can be economically irrigated or where storage reservoirs can be constructed to the best advantage. From the point of view of the engineer, however, it seems practicable not only to utilize for irrigation purposes all of the water flowing from the Blue Mountains in summer, but to store a large portion of the winter run-off and hold it for use during the growing season.

As is only too well known, the main obstacles to the full utilization of the water now running to waste in many arid regions—and southeastern Washington is no exception to the rule—is the rivalry of individual owners of land and of water rights. No general plan of using the summer flow from the Blue Mountains or of storing a part of the winter run-off can be carried out, however practicable it may seem to the engineer, until a large number of the owners of land in the region to be affected give their consent and cooperate in carrying out far-reaching plans for the public good.

In writing of the possibilities for irrigation in the region to the north of the Blue Mountains—and what has been said will apply also to large areas in the adjacent portion of Oregon—attention has been directed mainly to the canyon bottoms and to the ancient stream terraces. The engineer sees possibilities, also, in the direction of irrigating some portion of the wheat-land plateau between the deeply sunken stream channels.

To the northward of the Blue Mountains, more especially in Garfield and Asotin counties, the plateau surface rises gently toward the mountains, and in some instances could be watered by diverting the streams near their sources and before their channels became much depressed below the general level of the plateau. Little attention has been directed to the possibility of diverting the waters of the several branches of the Asotin, Alpowa, and Tokanon in their upper courses, and conducting them into the broad areas between the deep canyons of the main streams lower down, but this seems feasible to one making

a hasty examination of the region, especially if storage reservoirs can be established. The possibilities here referred to are illustrated at Anatone, about 14 miles southwestward from Asotin, where the water of George Creek, one of the tributaries of Asotin Creek, has been diverted with but trifling expense and carried to a nearly level area of rich wheat land conveniently situated for irrigation. This small experiment certainly suggests other possibilities in the same region. There is reason to believe that a careful survey would show available reservoir sites near the sources of several of the mountain streams, so situated that broad areas of the plateau could be watered from them.

At present little use is made of the water flowing from the Blue Mountains in comparison with what is possible from an engineering point of view. Small ditches have been made in a number of instances, particularly in the neighborhood of Walla Walla, for the purpose of irrigating gardens and orchards. In the lower portion of Walla Walla River about half a dozen water wheels arranged with buckets are in use. These raise the water from the river to a height of 15 feet and allow it to flow in ditches to orchard and garden lands. Each wheel is said to be capable of irrigating from 8 to 10 acres of land. In addition to these uses of the streams for irrigation by individuals a few attempts have been made by companies to construct irrigating canals.

What is known as the "Willis ditch," constructed by the Willis Land and Improvement Company, is taken out of the Walla Walla at the mouth of Mill Creek. The head of the ditch is in the southeast quarter of section 31, township 7, range 35, and extends westward 4½ miles, but is surveyed for 10 miles farther. This canal is 20 feet wide at the top and now carries 16 to 18 inches of water, but when in full operation is planned to carry a stream 2 feet deep. I have been informed that it now irrigates about 4,000 acres of land.

The "Hawley ditch" leaves the right bank of the Walla Walla at Raymo, and is 8 miles long, although only 4 miles are now in operation. It is said to carry 60 cubic feet of water per second, and to irrigate about 1,000 acres. When completed it is estimated that it will irrigate between 1,500 and 1,600 acres.

On the opposite side of Walla Walla River the Walla Walla Irrigation Company has constructed a ditch, beginning farther upstream, and now completed for about 4 miles, but it is not in operation. If the present plans are carried out, this ditch, when finished, will be in the neighborhood of 20 miles long and capable of irrigating some 4,000 or 5,000 acres of land.

In the canyon of Touchet River, about 4 miles above its mouth, a ditch has been constructed on the left bank of the stream. One and one-half miles below its head it is divided, one half being carried across the river to the left bank. Its capacity is about 60 cubic feet per second, and at present it is said to irrigate 2,000 acres.

Such information as is here given concerning the more comprehen-

sive plans that have been made for using the water of Walla Walla River and its branches was furnished by various gentlemen interested in the improvements mentioned. More detailed information could not be obtained, for the reason, in part, that some of the companies engaged in this work are involved in litigation growing out of the complex problem of riparian rights.

Snake River Canyon.—Snake River, although a magnificent stream, is not available for the irrigation of the surface of the plateau through which it flows, for the reason, as we have already seen, that it is deeply sunken in the rocks of the plateau. There are several areas in the bottom of the canyon, however, from a few acres to 300 or 400 acres in extent, which can be irrigated from the main river or by the waters of some of the tributary brooks and creeks. The soil at the localities referred to is river sand, exceedingly light and porous. It contains much mica and considerable lime, due in part to the presence of shells of fresh-water mollusks, and when irrigated is well adapted to fruit culture. Some of the finest fruit raised in Washington is grown on these sand bars, deep in the shelter of canyon walls.

The boldest scheme in the way of irrigation yet put into operation in southeastern Washington is one that was practically completed in 1896 by the Lewiston Water and Power Company, on the west side of Snake River, below Asotin. The canal referred to diverts the water of Asotin Creek, and carries it along the precipitous south side of Asotin Creek Canyon, and about the face of a bluff at the junction of this canyon with the broader canyon of Snake River, and northward along the steep side of the river canyon at an elevation of approximately 600 feet above the river. The canal is designed to furnish water for irrigating about 3,500 acres in Asotin County, Washington, and also 4,000 acres in Idaho, near Lewiston. The following facts concerning this important enterprise have been kindly furnished by Messrs. C. C. Van Arsdol and E. H. Libby, of the Lewiston Water and Power Company:

> The water is taken from Asotin Creek about 6 miles above its junction with Snake River, at an approximate elevation of 665 feet above Snake River, and is conducted 6¼ miles along the north slope of Asotin Creek by a flume 6 feet wide and 3½ feet in depth, with a grade of 10.56 feet per mile; thence to a point north of Swallows Nest Rock, a distance of 8 miles by canal, 6 feet wide on bottom, 16 feet wide on top, and 5 feet deep, with a grade of 2.12 feet per mile. Estimated capacity, 127 cubic feet per second. From a point near Swallows Nest Rock the distributing laterals diverge.

In the canyon of Snake River, above Asotin, there are narrow, detached strips of moderately flat land, having a width in some instances of 200 or 300 yards, composed of river silt and sand. These are nearly all on the west bank of the stream, and are bounded on one side by the swift-flowing waters and on the other by mountain-like walls of basalt from 2,000 to 3,000 feet high. A few of these narrow

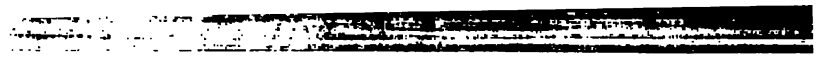
areas are now irrigated from small streams that come down the gulches in the canyon wall and are supplied by springs. In this portion of the canyon of Snake River the water of the river itself is not used for irrigation.

Below Lewiston there are also several localities where silt and fine micaceous sand brought down by the river has accumulated in sheltered portions of the bottom of the canyon. The largest of these areas now under cultivation is at the mouth of Wawawai Creek, which supplies water for its irrigation. At this locality about 300 acres are occupied by fine orchards of peaches, pears, prunes, etc. These orchards are wonderfully productive, and furnish fruit of large size and excellent quality. Between Wawawai and the mouth of Snake River there are about half a dozen localities at which from 8 to 14 acres of fruit land are under cultivation. The total amount of land in this section now being irrigated is in the neighborhood of 100 acres. At most of these localities water for irrigation is raised from the river by pumps operated by undershot water wheels, current wheels, located on rafts, as shown in Pl. V. These wheels are, I believe, all of one pattern. They are 18 or 19 feet long by 9 to 11 feet in diameter, and vary in effectiveness with variations in strength of current. One, owned by Mr. H. Gilbert, situated in section 26, township 11, range 33, at the time of my visit, August 19, was operating two suction pumps, each of which made 20 strokes per minute, and lifting about one-half gallon of water to a height of 27 feet at each stroke. At more favorable stages of the river the amount of water raised is doubled. The water is carried away in a small flume and irrigates about 1,000 fruit trees.

The difficulties that have to be contended with in this comparatively inexpensive method of irrigation arise principally from variations in the height of the river. The portion of Snake River here considered rises during floods from 20 to 32 feet above the mean low-water stage. The scows carrying the water wheels and pumps have to be moved from time to time to suit the varying height of the water. In winter the scows must be removed from the river to prevent destruction by floating ice. Dangers from driftwood have also to be guarded against, especially during high water.

The river sometimes rises during floods to within 3 or 4 feet of the cultivated lands, and there is danger at such periods that the river will remove the deposits previously made and thus destroy industries which it has required years to establish. This danger can probably be counteracted in many instances by planting willows and alders along the river banks. The inhabitants in Snake River Canyon should certainly take every possible precaution against unusually high floods in the river, as there is but a small margin between the usual spring rise and the surfaces of the sand bars where orchards and houses are located.

WATER WHEEL LIFTING WATER FROM SALMON RIVER FOR IRRIGATION



The Palouse country.—The surface of the wheat-land plateau north of Snake River, drained principally by Palouse River, is, as we have seen, a rolling, hilly region. Irrigation is there impracticable, except in the larger valley bottoms. Scarcely any irrigation is now practiced, and my examination of the region was too hasty to admit of an opinion in reference to what may there be possible. It seems probable, however, that here, as in many other portions of the arid and semihumid regions of the United States, the storage of water must eventually be resorted to.

A topographic map.—To those interested in the development of the many and varied industries of Washington, I venture to earnestly recommend the early completion of an accurate topographic map of the State. Such a map, in the sheets covering the more thickly settled areas, and where irrigation is desirable and practicable, should be on a scale of 1 mile to the inch, with contour lines showing relief of surface, drawn with 20-foot vertical intervals.

A knowledge of the drainage and topography or surface relief of a State is an important basis not only for irrigation but for planning country roads, railroads, canals, flumes, town water supply, etc., and in learning the best way to bring mines, timber, and agricultural lands in communication with markets. It is safe to say that the cost of nearly all public improvements and of many private enterprises would be greatly reduced if an accurate map of the State were available on which to base plans and estimates. The educational value of such a map, especially to school children in giving them a knowledge of home geography, is by no means the least of the useful purposes it would serve.

ARTESIAN WATER SUPPLY.

The small rainfall of southeastern Washington, and the fact that it is impossible to irrigate by far the larger part of the grain lands, or, in many instances, to obtain wholesome water for towns and even for farmhouses, from streams or ordinary surface wells, have led to the hope that a subterranean water supply might be discovered. In a number of instances marked success has attended the drilling of artesian wells, particularly in the eastern portion of Whitman County, and stimulated a desire to have similar experiments made elsewhere.

GENERAL CONDITIONS.

Before the expense incident to the drilling of deep wells is incurred it is desirable to give attention to at least two considerations: First, the conditions which render the obtaining of artesian water possible, and second, the geology of the region where it is proposed to drill a well. After a study of these questions in reference to a given locality one may predict with considerable confidence what measure of success is possible.

What are termed "the requisite and qualifying conditions of artesian wells" have already been fully explained in the publications of the United States Geological Survey,[1] and it does not seem necessary to restate them at length in this report.

Briefly stated, an artesian well is one in which water rises under the influence of the pressure of water at higher levels. The suggestion that water sometimes rises in a well or boring on account of gas pressure need not be discussed at this time.

In an artesian well the water sometimes rises to the surface and overflows, or it may be under sufficient pressure to form a fountain-like jet above the surface; in other cases the water rises some distance in the well, but fails to reach the surface. In all these instances the well is classed as artesian. The question of surface flow is determined not only by the pressure acting on the water but by the elevation of the surface at the mouth of the well. For example, a well drilled in a valley might reach a water-charged layer of rock in which the water is under sufficient pressure to cause it to rise fountain-like above the surface; while a well drilled on a neighboring hill and reaching the same water-bearing layer would be only partially filled. If in such instances the casing or pipe of the lower well be continued upward, its top remaining open, the water will rise within it to the same level at which it stands in the well drilled on the neighboring hill; that is, the water is under the same pressure in each instance. I make this explanation in reply to numerous questions asked me during my field studies, as to whether an artesian well is necessarily a flowing well or not. In brief, an artesian well is one in which water rises under pressure; if the water overflows the surface, it is convenient to designate it as a flowing well.

In order that water may rise in a tube drilled in the earth it is necessary for it to be under pressure; in other words, the water must be confined so that it can not flow away and thus relieve the pressure. The most common conditions under which this happens are these: Certain layers of rock of loose texture, as sand and sandstone, become water-charged, and the water is confined in them by other layers above and below which are impervious to water, such as clay. If a water-charged layer of sand between two layers of clay is inclined, the water will percolate through it. If the central portion of such a water-charged sheet is depressed, the water in the surrounding portions will tend to flow toward the depressed central area. The water in the central portion will then be under the pressure of the water in the more elevated portions of the porous layer. Evidently, under such conditions, if a hole is made from the surface through the upper layer of clay, it will allow the water to rise to the surface, or until it stands as high as the lowest outlet in the rim of the basin. These

[1] The requisite and qualifying conditions of artesian wells, by T. C. Chamberlain: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 125–173. Residents of Washington may find it profitable to consult also: "General principles pertaining to artesian water," in A Geological Reconnoissance in Central Washington, by I. C. Russell: Bull. U. S. Geol. Survey No. 108, 1893, pp. 32–36.

conditions are illustrated in the following ideal section across an artesian basin:

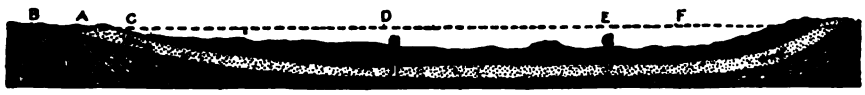


FIG. 2.—Ideal section illustrating the chief conditions of artesian wells. A, a porous stratum; B and C, impervious beds below and above A, acting as confining strata; F, the height of the water level, "artesian head," in the porous bed A, or, in other words, the height of the reservoir or fountain head; D and E, flowing wells springing from the porous water-filled bed A. (After T. C. Chamberlin.)

In nature we find examples of what, for convenience, may be termed incomplete artesian basins; as, for instance, when an inclined pervious bed, a layer of sand, we will say, thins out on its lower edge and allows the sheets of impervious rock above and below it to come together. An ideal example of this character is shown in the following cross section:

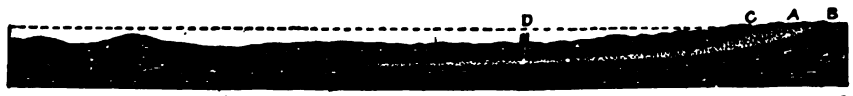


FIG. 3.—Ideal section illustrating the thinning out of a porous water-bearing bed, A, inclosed between impervious beds, B and C, thus furnishing the necessary conditions for an artesian fountain, D. (After T. C. Chamberlin.)

If the layer of sand is penetrated by a well drilled at D, the water will rise in an open tube to a height regulated by the pressure of the water in the sand above the locality where the well reaches it.

The source of the water that rises in artesian wells is mainly the precipitation on the edges of the pervious beds where they come to the surface. In some instances the porous beds are charged in this way at their outcrops, hundreds of miles from where the water is liberated by drilling wells.

The height to which water rises in an artesian well, or, in the case of a flowing well, the height to which it would rise in a tube open at the top, if properly attached to the well, is termed the "artesian head." This is illustrated in the waterworks of towns, where the water rises in the distributing pipes to the same level as the surface of the water in the reservoir from which it is drawn.

From this brief outline of the leading conditions which favor the possibility of obtaining artesian water it will be seen that the task of the geologist in this connection consists in ascertaining whether alternating sheets of pervious and impervious rocks exist in the regions he studies, and, if the requisite succession of beds is found, whether the beds are so inclined as to bring a portion of the water in the pervious layers under the pressure of other portions. In addition, the amount of rainfall and the quantity of water brought by streams to the outcrop of the porous beds; whether the impervious beds are broken; the changes which layers of rock undergo from one locality

to another; the depth to which the pervious layers have been eroded by streams; and several other limiting and qualifying conditions have to be considered and investigated.

LOCAL CONDITIONS.

In southeastern Washington and adjacent portions of Oregon and Idaho the rocks, as already described, belong in two series: First, the crystalline or metamorphic and igneous rocks, consisting principally of granite, schist, quartzite, and diorite, forming the mountains of western Idaho; and second, the lava sheets and interleaved sands and clays forming the wheat-land plateau and the Blue Mountains.

So far as the question of obtaining artesian water is concerned, we may dismiss the regions where the metamorphic rocks and diorite form the surface. The original bedding in these rocks has been almost entirely obliterated by the changes they have experienced, and there is no succession of porous and compact layers. The rocks have been folded and broken by joints, so that practically none of the requisite conditions for retaining water under pressure are present. The fissures and cavities in these rocks are probably, in many instances, water-filled, so that wells drilled at the proper localities might allow the water in them to rise and possibly to overflow the surface. But these cavities are irregular, and, as far as can be judged, seldom present the conditions just mentioned. It is impossible for anyone to predict where such water-filled cavities exist, and the drilling of a hole in the rocks with the hope of finding one is to take one chance in a million.

The areas where granite, schists, quartzites, and diorites are exposed or occur a short distance below the immediate surface are therefore to be avoided in all attempts to obtain artesian water.

In the region occupied by the Columbia lava the rocks, although for the most part of igneous origin, are in well-defined layers. Between the sheets of basalt, as the reader is already aware, there are layers of sand, volcanic dust and lapilli, and clay. This series of beds, although apparently horizontal over broad areas, is in reality in many localities slightly inclined. Conditions favorable to the hope of obtaining artesian water are thus suggested.

The basalt is not porous, except very imperfectly at the junctions of many of the layers, where it is scoriaceous, and it can not be considered as a pervious rock. It is traversed by innumerable joints and seams, and evidently could not retain water under pressure. In itself, therefore, the basalt presents no condition that would encourage the hope of finding artesian water.

When sheets of sand and clay intervene between the layers of basalt, and the series is slightly tilted, more hopeful conditions evidently result. These conditions are fulfilled in a belt of country, some 10 or 15 miles broad, along the eastern border of Washington, north of Snake River, and extending at least as far as the northern boundary of Whitman County, and possibly all the way to Spokane River.

The westerly inclination of the rocks in this section is extremely gentle, and, although not yet measured, may probably be taken at about 5 feet to a mile. The artesian head is consequently low, and it is only in the deeper valleys—which, however, have not been cut through certain strata of clay—that flowing wells can be obtained.

EXISTING WELLS.

The information here presented concerning the wells that have been drilled in southeastern Washington has been obtained from various persons who were especially interested in the results hoped for, but was furnished principally by Mr. A. L. Ebersol, of Garfield, Washington. Mr. Ebersol began his work as a well driller in the oil fields of Pennsylvania, and has had several years' experience in putting down wells under contract in Washington.

Wells at Pullman.—Pullman is situated partially in a narrow, steep-sided canyon, cut in the basaltic plateau by one of the several branches of Palouse River. The bottom of the now partially filled canyon is about 200 feet below the general level of the plateau. The college buildings situated near the summit of the hills overlooking the business portion of the town are 220 feet above the station of the Union Pacific Railroad, which, as shown by railroad surveys, is 2,340 feet above the sea.

Fifteen wells have been drilled at Pullman, some of them in the bottom of the canyon and others on its borders. Those in the bottom of the canyon, 11 in number, are flowing wells, but those on the sides of the canyon above an elevation of about 2,365 feet do not overflow; that is, the pressure on the water in the pervious stratum penetrated by these wells is sufficient to raise it to a level of about 25 feet above the canyon's bottom.

The hills bordering the canyon at Pullman are of basalt, which appears to be a single flow, and so far as can be ascertained by observation and the use of a pocket level is horizontal. Beneath this heavy sheet of basalt is a stratum of clay, 25 to 30 feet thick, the upper surface of which has been hardened and rendered dark in color by the heat of the basalt spread over it. Below the clay is a layer of basalt 60 feet thick; then comes a layer of granitic sand, which has been penetrated to a depth of about 12 feet without reaching the bottom. This sand is unconsolidated and abundantly water charged.

It is reported that some of the wells furnished artesian water as soon as the clay layer was penetrated and that the volume increased until the sand was reached. This seems to indicate that the water rose through fissures and seams in the basalt, but not with sufficient freedom to furnish the desired supply. The impervious layer is evidently the clay stratum, and the pervious layer is the loose, unconsolidated sand. Sand is thrown out of the flowing wells, and samples collected show that it is mainly quartz sand, with occasional fragments of granite and basalt and much mica. This material is mainly such as would

be furnished by the disintegration of the quartzite and granite forming the hills bordering the basaltic plateau on the east. With the quartz sand are mingled grains of basalt, which sometimes give it a dark color.

The first well drilled, that now supplying the Palace Hotel, as stated by M. C. True, the owner of the hotel, was finished in May, 1894. It has a total depth of 77 feet, and reached flowing water at 65 feet. It is 6 inches in diameter, and furnishes about 30,000 gallons per day. The well, beginning at the surface, passes through 12 feet of soil and cobblestone and 53 feet of solid basalt, and after passing through the basalt it reaches about 12 feet in the sand beneath. The elevation at the surface is that of the general level of the canyon bottom, or 2,340 feet. The water rises in pipes about 20 feet above the mouth of the well.

On the opposite side of the street from the Palace Hotel a well was drilled for J. R. Ruply in 1889 to a depth of 73 feet. This well is said to have been drilled in solid basalt, with the exception of the first 8 or 10 feet, which consisted of soil and loose rocks. The report fails to mention the stratum of clay which outcrops in the sides of the canyon near at hand, and which probably exists beneath the surface alluvium throughout the lower part of the town.[1] The Ruply well is 6 inches in diameter. It reached a stratum of micaceous sand, and water rose well above the surface, as is shown in the photograph here reproduced.

The well which supplies the town of Pullman was drilled in 1890, and is 6 inches in diameter and 84 feet deep. The surface level is practically the same as that of the Palace Hotel well. The section passed through is reported to be as follows: Surface soil, 3 feet; clay, 10 feet; basalt, 60 feet; gravel and sand with lignite, 11 feet. The bottom of the layer of sand was not reached. Water rose in an open pipe 20 feet above the surface, or to a level about 2,360 feet above the sea. No decrease in the pressure has since been observed. The water is raised by steam pumps to a reservoir on an adjacent hill and from there distributed for domestic and town purposes.

The three wells just described are typical examples of the eleven flowing wells now in operation in the lower portion of Pullman. The wells on the sides of the canyon, which were begun above the artesian head of the water in the porous stratum, are illustrated by the one which supplies the college buildings. The surface level at this well, as shown by measurements with an aneroid barometer, is 30 feet above the general level of the street in the lower portion of the town, or 2,370 feet above the sea. The well has a total depth of 144 feet, and is reported by Mr. Ebersol, the contractor, to have been all in basalt, except about 30 feet of clay. The clay layer is reported to

[1] In the report obtained of several other wells in Pullman all reference to this clay stratum is omitted. A possible reason for this omission is that the price of drilling is usually varied with the character of the material passed through.

ARTESIAN WELL AT PULLMAN

ave been reached at 65 feet below the surface. The section exposed
n the valley of the canyon, however, indicates that the clay should
ave been first encountered at about 25 or 30 feet below the surface.
Vater rises to within 6 feet of the surface and is pumped to a reser-
oir which supplies the college buildings, situated about 200 feet
igher than the surface at the well.

It does not seem advisable to record at this time all of the reports
btained concerning the wells at Pullman, as careful records of the
naracter of the rocks passed through were not kept, and in some
nstances the reports obtained are unsatisfactory for other reasons.

The wells are all 6 inches in diameter. The contract price for
rilling in surface earth and clay was in general $1 per foot, and in
asalt $4 per foot. The water in all cases is beautifully clear, with-
it occluded gases, and, with the exception of the Palace Hotel well,
soft. The water of the exceptional well has not been analyzed, but
s taste suggests the presence of iron. None of the wells are cased,
ut much loss from leakage through fissures in the basalt is prevented
y the clay stratum near the surface. The wells in the lower part of
ne town begin in the clay or in superficial deposits resting on it. It
, to be expected that westward from Pullman, where the branches of
alouse River become deeper, the clay layer has been cut through,
nd that the conditions favorable for obtaining artesian water will be
npaired, for the reason that basalt allows water under pressure to
scape through fissures. In such instances it is evident that all wells
nould be cased down to the water-bearing sands.

Several of the wells at Pullman are allowed to flow, thus wasting a
rge volume of water and decreasing the pressure. If the blessings
ccompanying the discovery of an excellent water supply are to be
naintained, all wells should be closed when not in use.

Wells at Moscow, Idaho.—At Moscow, Idaho, about 9 miles east of
'ullman and near the junction of the Columbia basalt with the granite
ills bordering it on the east, several wells have been drilled.

I have been informed by Mr. Ebersol and others that fourteen wells
ave been drilled since 1890, and that ten of these were flowing in 1891,
ut since then the pressure has so decreased that the water now stands
or 9 feet below the surface. The depth of these wells is in general
bout 100 feet, the first 50 to 60 feet being through loose material—
he alluvial filling of the valley—and the remainder in basalt.
Vhether a layer of sand was reached or not seems uncertain. The
nformation available concerning these wells is meager and unsatis-
actory, but it seems that the alluvium of the valley—much of it fine,
lay-like soil—plays the rôle of an impervious layer and retains water
nder pressure in the seams and joints of the basalt, thus furnishing
n approach to favorable artesian conditions.[1]

Wells at Palouse.—Four wells have been drilled within a radius of

[1] It is probable that if these wells were properly cased a surface flow would result.

about 20 feet in the business portion of Palouse, with the hope of obtaining a water supply for the town. The last was completed in 1894. The town is situated principally in a valley with precipitous borders 280 feet high. The wells are in the bottom of the valley, and are said to be about 200 feet deep and to penetrate material as follows:

	Feet.
Earth and stones	14
Coarse gravel	3
Solid basalt	100
Coarse sand	9
"Black slate rock"	30
Sand, water-bearing	25 to 30

Of these four wells, the first drilled is now closed, and the remaining three discharge collectively about 10 gallons per minute. The wells are 8 inches in diameter at the top, but are said to decrease to 6 inches, and again to 2 inches toward the bottom.

The wells are a failure so far as supplying the town is concerned, but it is evident that if casings could be introduced their efficiency would be increased.

Well at Garfield.—A well has been drilled at Garfield with the hope of obtaining artesian water for the town, but did not meet with success. The well is reported to have been drilled to a depth of about 300 feet with a 6-inch bit, and afterwards enlarged by excavating to 8 feet to a depth of 100 feet. From this well water is now pumped for the supply of the town. The excavated portion of the well passed through earth and bowlders; apparently the upper part of this material is a stream deposit and the lower portion disintegrated basalt. Below the open well the drill passed through "honeycomb" rock; by this is probably meant much-jointed and possibly scoriaceous basalt.

James Walter's well.—Three miles northeast of Garfield, at the residence of Mr. James Walter, a drilled well 113 feet deep was completed in 1892. This is a flowing well, and discharges a stream of water 1¼ inches in diameter. The section passed through is reported by Mr. Walter as follows:

	Feet.
Dirt	16
Basalt	65
Blue clay	5 to 6
Gray clay	5 to 6
Hard cement	2
Blue and yellow clay, with quicksand, water-bearing	10 to 12

The surface of the ground at the locality where this well was drilled is reported to be higher than Garfield, but no measure of its elevation is available.

Other wells.—Incomplete reports have been obtained of not fewer than a score of wells, in addition to those mentioned above, in a belt of country about 15 miles wide, extending northward from near Snake

River, along the eastern border of Washington. The time available for making a personal examination of this region was so limited that little more than the facts here reported could be obtained.

The success which has followed a large number of the attempts already made to obtain artesian water in this region, and the facts learned concerning the nature and relations of the rocks, certainly indicate that artesian water can be had at a moderate depth over a wide extent of rich agricultural land.

The western border of the region in which artesian water can be had is indefinite. The region to the west of a north-and-south line passing through Garfield, including the greater part of Whitman County and all of Adams and Franklin counties, is geologically unknown, except so far as the conditions there prevailing can be judged from what has been seen in adjacent areas. Whether test wells have been put down in this region or not I have failed to learn.

There is no definite evidence in hand to show that the sands and clays penetrated at Pullman, Garfield, etc., extend far westward, but it is reasonable to suppose that such is the case. It is probable also that layers of clay and sand exist lower in the series than those penetrated at Pullman, which may furnish similar conditions in the region to the west.

Besides the presence or absence of pervious and impervious layers, the dip of the beds and the depth to which they have been dissected by streams have also to be considered. While there seems a probability that artesian wells may be had over a wide extent of country to the west of the region at present explored, lack of definite information concerning that region makes it impossible for one to form an opinion in this connection.

ARTESIAN CONDITIONS SOUTH OF SNAKE RIVER.

The question of obtaining artesian wells in that portion of Washington which lies south of Snake River resolves itself into two considerations with reference to source of supply: First, can water be had under conditions similar to those existing at Pullman from strata leading westward from the mountains of Idaho? Second, are there water-bearing strata dipping away from the Blue Mountains?

With reference to the first of these questions, it is to be remembered that Snake River Canyon cuts off all possible sources of supply to a minimum depth of about 2,000 feet below the general surface of the basaltic plateau. We have only indefinite evidence as to the nature of the rocks below the level of Snake River. As the basaltic layers exposed in the canyon of that river are nearly horizontal, it is evident that the artesian head for any porous layers which may exist below the horizon of the river would be low. The manner in which the series of horizontally bedded basaltic sheets abuts against the metamorphic rocks on the east renders it extremely improbable that

any deeply seated porous stratum could be water-charged in such a manner as to make it a source of artesian water.

The considerations just indicated are of such weight that there seems no need of hesitation in declaring it useless to hope for success in drilling wells in the region south of Snake River with the view of obtaining water from sources similar to those which supply the wells in the neighborhood of Pullman.

Turning to the second possible source of artesian water suggested, namely, the Blue Mountains, we find that the rocks dip away from that uplift, and also that they are abundantly water-charged. Two of the primary conditions requisite for obtaining subterranean water under pressure are thus fulfilled. Inquiries in at least two other directions must be made, however, before a conclusion can be reached. These are: First, are there layers of clay and sand interbedded with the basalt? and second, have the rocks been so deeply dissected by streams as to allow pervious beds, if they exist, to be drained?

Beds of clay and of fragments of volcanic rock (lapilli and volcanic dust) interbedded with basalt occur in the neighborhood of Asotin, and possibly extend southwestward and westward, but no exposures of these layers were seen by me in the Blue Mountains. My examination, however, was not sufficiently detailed to prove that they are there absent.

The material forming the clay beds referred to was derived from the mountains of Idaho before the cutting of Snake River Canyon, and probably thin out westward. No layers of sand like the one yielding water at Pullman are known to occur beneath the clays, and the strata of lapilli and volcanic dust are not sufficiently porous to be classed as water-bearing strata. It is thus exceedingly doubtful if the succession of beds in the flanks of the Blue Mountains affords the arrangement of pervious and impervious layers necessary for an artesian water supply.

With reference to the depth to which the rocks forming the Blue Mountains and the plateau extending northward from them have been dissected by streams, it will be remembered that deep erosion has occurred. In the mountains there is a veritable labyrinth of canyons from 2,000 to 3,000 feet deep. This deep erosion, however, is favorable to the process of charging with water any pervious layer that may exist in the flanks of the range, since the edges of the layers are exposed to the rain and to water flowing down the sides of the canyons or percolating through the soil that mantles the cut edges of the strata.

The canyons leading northward from the Blue Mountains soon increase in depth, and the plateau in the northern portions of Garfield and Columbia counties is deeply dissected. Evidently any porous strata that are cut by these canyons could not contain water under pressure. The only possible hope for obtaining artesian water in the *counties* just mentioned is, therefore, below the level of the canyon

bottoms. The expense of drilling wells from 500 to 2,000 feet deep through basalt, as would of necessity be the case on the fragments of the plateau remaining between the streams, even if success at these depths were assured, would preclude the use of water thus obtained for irrigation.

In the canyons there is a chance that artesian water might be reached, but the conditions are so uncertain that the experiment of sinking wells below a depth of 100 or 200 feet should not be made, except as a last resort. The more practical and entirely feasible method of utilizing the surface streams within the canyons makes it unwise to incur expense in the search for subterranean water. The possibility of obtaining water from the alluvium of the canyons will be referred to later.

In the valley of the Walla Walla, in a general way westward of a line connecting the cities of Walla Walla and Milton, Oregon, there is an absence of canyons. In this region, also, there is at least one clay stratum interbedded with the basalt, but no evidence of the presence of layers of sand has been obtained. This is the only region in Washington south of Snake River where the hasty examination I have been able to make suggests the possibility of obtaining artesian water at reasonable expense and where there are lands available for farming. Even in this region the certain method of utilizing the abundant surface water is much to be preferred to the uncertainty of attempting to obtain flowing wells. The geological conditions in the valley of the Walla Walla are not such as to warrant the prediction that success would follow the drilling of a well, but simply that there is a possibility of success. The best locality for drilling a test well in this region is in the vicinity of Whitman. A trial made at Walla Walla would probably be equally decisive. At Whitman a depth of 150 to 200 feet of surface material would probably have to be passed through before rock in place would be reached, but in this upper portion of the section flowing water is likely to be met. At Walla Walla the superficial material—the bowlder and gravel of Mill Creek—is apparently not deep and might also yield flowing water.

In order to test the possibility of obtaining water at Walla Walla I should favor the project, already proposed, of drilling a well at the State penitentiary. To make the test conclusive, the proposed well should be drilled to a depth of 500 feet, if flowing water is not obtained nearer the surface.

WELLS IN ALLUVIUM.

There are flowing wells of another class that require mention, but which are scarcely to be classed with true artesian wells.

The deposits made in stream channels and over flood plains are usually composed of irregular layers of bowlder, gravel, sand, clay, etc., through which the stream waters percolate. The water in the pervious layers is sometimes under moderate pressure and will rise

to the surface when wells are dug. The pervious beds are usually irregular and of small extent, and their water supply, being furnished by the stream which deposited them, varies with changes in the volume of the stream. No one can tell, without making practical test, whether the percolating waters in an alluvium-filled valley will rise to the surface or not. The best way to search for such waters, where the alluvium does not contain large bowlders, is by driving pipes into the ground. Where bowlders 1 foot to 2 or 3 feet in diameter are met with, driven wells are impracticable. It is also difficult and expensive to drill through deposits of bowlders, so that the only practicable method seems to be to make the excavation by hand. In some instances, when a strong flow of water is reached, if the bottom of the well is covered with cement, through which a pipe is inserted leading to the surface, a surface flow may be obtained.

As is well known, the bottom of many of the canyons leading from the Blue Mountains are deeply filled with alluvium, in which water may be obtained. An excellent method of conducting the percolating water of alluvial deposits to the surface and making them available for use lower down the valley in which they occur, without pumping, is in operation at Walla Walla.

WATERWORKS AT WALLA WALLA.

Walla Walla is now supplied with water from infiltration ditches prepared in the coarse gravel that forms the flood plain of Mill Creek, about a mile above the central part of the town. The water from the infiltration ditches is conducted into reservoirs, from which it is distributed by gravity. The fall of Mill Creek in the vicinity of Walla Walla is 63 feet per mile. This rapid descent makes it possible to locate reservoirs near the town. The infiltration ditches are dug as open ditches to a depth of from 12 to 15 feet. At the bottom an inverted trough made of planks is placed and covered with clean gravel to the depth of several inches. The gravel also fills the space between the sides of the inverted trough and the undisturbed material forming the walls of the ditch. The material removed in digging the ditch is then replaced. The use of tiles in place of the inverted wooden trough would have advantages, but would be more expensive.

The infiltration ditches are located at angles of 30° to 40° with the direction of slope, and trend upstream. The water percolating through the gravel enters the inverted troughs from below and also flows through the loose gravel covering them, and is conducted to reservoirs. The length of the infiltration ditches varies. As an example of their efficiency I insert the following information, furnished by the superintendent of the waterworks, concerning what is termed "Reservoir No. 2." This reservoir is a tank excavated in the gravel, but not lined, and sheltered by a timber and shingle roof. It is rectangular, measures 51 by 90 feet on the sides, and is 10 feet

leep. Two infiltration ditches lead to this tank, one 500 and the other 800 feet long. These discharge during the summer season about 320,000 and 420,000 gallons, respectively, per day.

There are two other reservoirs of similar dimensions, supplied in like manner. The water reaching the reservoir is thoroughly filtered, and at present, as shown by sanitary analyses, is wholesome and of an agreeable temperature.

This method of obtaining a water supply is recommended for its economy, and on a smaller scale might be advisable in many instances for farm purposes, in place of wells now commonly in use. The advantages over surface wells are that the water supply may be drawn from a distance from sources of contamination, and when properly arranged the trouble and expense of pumping are avoided.

The only objection that can be suggested to this method of supplying towns or residences with water is that it comes from superficial deposits and is in danger of contamination from houses, stables, etc., situated upstream from where the infiltration ditches are located. In countries of small rainfall, where the streams are greatly lowered during the summer, the dangers from these sources are multiplied. For 9 or 10 miles above Walla Walla the narrow canyon-like valley of Mill Creek is occupied somewhat thickly by farmhouses and stables. Contamination of the city water supply from these sources is a constant menace.

CONCLUSIONS.

The results of the hasty examination of the geology of southeastern Washington here reported on, so far as the question of artesian water is concerned, may be briefly summed up as follows: In the Palouse country there are reasons for believing that the area in which artesian water has been found will be broadened westward. South of Snake River there is no evidence that success would accompany the drilling of wells on the uplands. In the canyon bottoms there is a possibility of finding artesian water, but further than this the study of the geology does not offer suggestions, except of an adverse character. The chances of failure far outbalance the chances of success. To the northwest and west of the Blue Mountains—more definitely, in the valley of the Walla Walla westward from a line joining the towns Walla Walla and Milton, and possibly extending some distance into Oregon—the conditions are more favorable than elsewhere in Washington south of Snake River and warrant the drilling of a test well should the demand for water be great. Even in this most favorable area, however, I should recommend the full utilization of the streams and the storage of the winter run-off before attempting to obtain artesian water for irrigation purposes.

AN OUTLINE SKETCH OF THE GEOLOGICAL HISTORY OF SOUTHEASTERN WASHINGTON.

Of the ancient geological history of Washington but little is known. The northern portion of the Cascade Mountains, as shown recently by Bailey Willis, is largely composed of metamorphic rocks. Similar rocks occur about Lake Chelan and north of the Big Bend of the Columbia and of the lower portion of Spokane River. From Spokane the hills formed of these metamorphic rocks extend southward along the Washington-Idaho boundary, and from them the mountains of western Idaho have been sculptured.

The rocks just referred to as being of metamorphic character—that is, greatly changed by heat and heated solutions from their original condition—were in many instances of sedimentary origin, but are now granite, schist, quartzite, etc. The granites, however, may be in part of igneous origin—that is, were once in a molten condition—but of this no direct evidence has been observed. The place in the earth's history where these rocks belong is unknown, but their crystalline condition suggests that they are very old, and possibly belong to the series termed Archean. The resemblance of metamorphic rocks in one region to similar rocks at a distance is an uncertain basis for classification, however, for the reason that strata belonging to widely different periods, when changed by heat and heated water, produce granites, schists, etc., having the same characteristics. Some of the granites of the Pacific Coast are known to be of comparatively recent geological date.

The structure of the rocks of the metamorphic regions of Washington—that is, the positions which the rocks occupy, whether folded, contorted, broken, etc.—is not well known, although it is easily seen that those which still retain evidence of bedding, and were without question originally in horizontal sheets, have been upturned and bent into great folds. Throughout the metamorphic region the country is mountainous, and much of the geological history of the region is recorded in their forms. The valleys have been carved out of the upraised mountain masses, and each dome and crest has been slowly fashioned by rain, frost, wind, and rills into its present transient shape. The depth to which the valleys have been excavated and the forms of the bordering hills show that the mountains are old and have formed a land surface for geological ages.

In comparatively recent geological times the mountains of northern Washington and eastern Idaho, although probably higher and more rugged than now, had their present general outlines, but the central and southern portions of the Cascades, as well as the Coast Range, were as yet unborn. The country south of the southward-facing semicircle of mountains, embracing the present great plain of the Columbia and southeastern Washington, was low and partially submerged at times beneath the sea. This vast low-lying area,

together with the surrounding mountains, was clothed with varied and beautiful forests, resembling those of the South Atlantic States at the present day. In this valley region, which extended far south, there were lakes and swamps in which vegetable matter accumulated and was later changed to coal. Some of this coal is now mined at Roslyn. The luxuriant vegetation, a part of which has been preserved as coal, furnished food and shelter for a variety of animals, no near relatives of which are living at the present day.

This age, when almost subtropical conditions prevailed, was in the early Tertiary. As time passed, the lakes became filled with sediment, and much of the region sank beneath the sea. Clays and sands were spread out which have since hardened into rock. Upheaval brought these once level sheets of rock above the sea and raised them into a mountain range—the southern Cascade. In central Washington these early Tertiary rocks were eroded, and outbreaks of volcanic energy caused lava sheets to be spread over them. Fissures opened in the earth's crust, and molten rock was poured forth in such wondrous abundance that thousands of square miles of valley lands were inundated by the fiery floods. The lavas were similar to those poured out within the past few years by the volcanoes of the Hawaiian Islands and other regions. The molten rock was highly liquid, flowed rapidly, and spread out in sheets of broad extent. On cooling, it formed the dense, black basalt now so familiar throughout central and southeastern Washington. This is the Columbia lava, so frequently mentioned on the preceding pages.

Vast outwellings of molten rock occurred at intervals throughout a period embracing many hundreds and probably many thousands of years. The time between successive flows was sufficiently long, in numerous instances, to allow the surface of the cooled and hardened lava to crumble and decay under the action of the atmosphere and form soils on which forests of oak and pine took root and flourished. In some instances abundant showers of volcanic dust, similar in character to the fine dust-like material blown out by many volcanoes in historic times, covered the land and buried the still erect trees. Later lava sheets were spread over the entombed forests, and in some localities charred the trees and changed them to charcoal. When the trees were so protected by their covering of volcanic dust that they were not directly influenced by the heat of the lava that flowed over them, heated waters brought silica to them in solution, and they were changed to stone. The stumps of these silicified or fossilized trees, still standing as they grew, may be seen in the sides of the canyons that streams have cut in the thick pile of lava sheets. The replacement of the wood in these buried forests by silica, usually in the form known as opal, was so complete that not only the grain of the wood but each duct and cell is preserved, and when examined in thin sections under the microscope it appears as perfect as the wood of a living tree.

Lava flow succeeded lava flow until the vast valley region embraced

in part by the mountains of northern Washington and eastern Idaho, thousands of square miles in extent, was covered with basalt to an average depth of probably 3,000 or 4,000 feet. The molten rock spread widely over the lowlands and about the bases of the bordering mountains and extended up the tributary valley. As sheet after sheet was added the hills in the lowlands became buried; outstanding spurs of the mountains became capes in the sea of molten rock; isolated mountain peaks were surrounded by the fiery flood and submerged, or left as islands rising above its surface.

This vast inundation of lava is one of the most remarkable and, I may say, one of the most dramatic incidents in the geological history of North America. It is safe to assume that all the lava poured out by volcanoes within historic times, if run together, would make but a small fraction of the mass under which the region drained by the Columbia is buried.

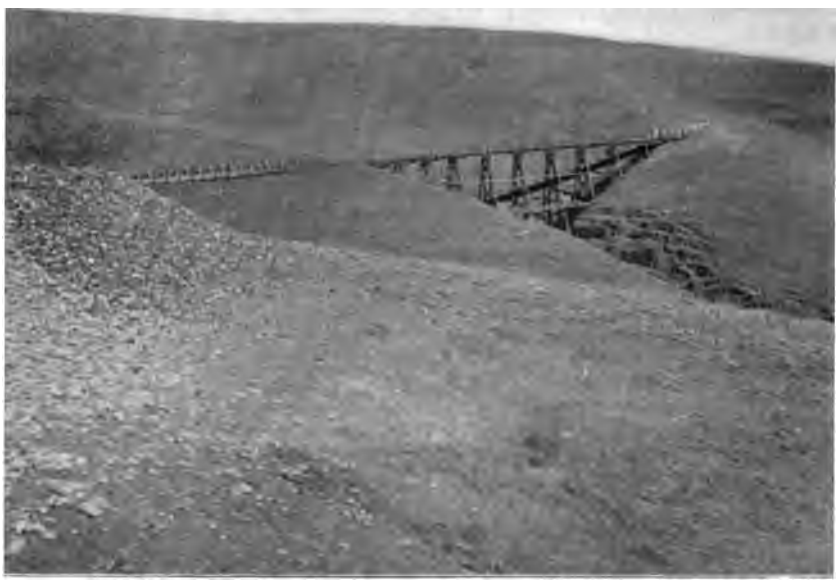
During the lava flows streams from the bordering mountains met the encroaching sheets of molten rock, and many grand spectacles of conflict between water and fire might have been witnessed, but of the presence of man on this continent at the time of these vast eruptions we have no records. Some of the sheets of volcanic fragments interbedded with the lava sheets appear to have been formed by the shattering and rapid cooling of the highly heated rocks on coming in contact with water.

Layers of fine, pure-white volcanic dust between the sheets of basalt show that distant volcanoes were in a state of violent eruption at the time these deposits were made, and the wind carried the dust far and wide over the land. That the dust did not come from the same eruptions that supplied the basalt is shown by marked differences in chemical and mineralogical composition. The dust is an acid rock—that is, rich in silica—while the basalt is basic.

During the intervals between the lava flows lakes were formed on the surface of the cooled basalt and sheets of sediment were laid down. These lakes came into existence, especially about the borders of the lava-covered country, for the reason, in central and eastern Washington at least, that the advance of the lava was toward the mountains, and on cooling formed land surfaces which sloped gently toward the uplands and intercepted their streams. In some instances the lava flowed far up the valleys and gave them a nearly level floor of solid basalt. Sand and gravel, swept out of the mountains by swift-flowing streams, was spread over the lava during intervals between the fiery floods. Alternating sheets of basalt, sand, and clay were thus formed, especially about the borders of the lava-covered region, and furnished the requisite conditions for storing water under pressure. Artesian wells ages later were thus made possible.

Toward the close of the long period during which the lava sheets were spread over the lowlands the lakes formed on their surface

LEWISTON IRRIGATION CANAL



FLUME IN LEWISTON IRRIGATION CANAL

became of broad extent, but were invaded from time to time by additional layers of volcanic rock, which were buried by still younger lacustral deposits. At length the volcanic energy ceased and deep and widely extended lacustral sediments were accumulated. The broad lakes in which these sediments were laid down in even layers were probably held in basins formed by the upheaval of the Cascade Mountains. The light-colored and evenly bedded deposits referred to may now be seen at the White Bluff of the Columbia, in Wenas and Natches valleys in Washington, and in John Day Valley in Oregon. Leaves of many kinds of trees and the bones of mammals occur in these deposits and record the fact that after the vast outpourings of lava came to an end the land was again forest covered and inhabited by many large animals, all of which are now extinct. Thick layers of volcanic dust interleaved with the lacustral clays and sands bear evidence of violent eruption in distant volcanoes.

With the drainage of the lakes that covered large portions of the lava country with sands and clays, the streams from the mountains flowed to the sea, and were enabled to carve canyons in the hard lavas. At an early stage in this epoch stream-borne gravels were carried out onto the basaltic plateau, and the most resistant of the stones thus deposited—the hard quartzite—may still be found in many places on the general plateau surface between deep canyons.

Snake River slowly carved out its channel until, at the present time, in the eastern flank of the Blue Mountain uplift it is an immense gorge some 15 miles broad at the top and about 4,000 feet deep. The work of stream cutting is slow. If we could study Snake River for a century where it flows over hard basalt, it would be difficult to determine the depth—probably not over a fraction of an inch—that it had lowered its bed. The river performs this task mainly by abrasion. Stones and sand swept along by the current wear the rocks over which they pass. Basalt is dense and hard, and, although decomposing with comparative rapidity when exposed to the air, yields very slowly to mechanical wear. The task of cutting to its present depth the magnificent canyon which now excites the wonder and admiration of all who behold it must have required an almost infinite time, as it appears to us. This task has been performed, however, since the lava sheets were spread out over southeastern Washington, and for the most part since the lake beds containing the records of extinct floras and faunas resting on the lava were laid down.

There are reasons for believing that the canyon of Snake River was excavated to its present depth before the time in the earth's history known as the Glacial epoch. Space will not permit of a review of all the facts that lead to this conclusion, but a great gravel terrace in the canyon of Snake River and similar terraces in the canyons of Columbia and Spokane rivers show that after they were worn to their present depth they were filled to a height of 300 or 400 feet—360 feet in the case of the Snake River below Lewiston. This filling is attributed

to the overloading of the streams with débris furnished by glaciers and by swollen mountain streams. The cause of this change was climatic. During the Glacial epoch Washington and Idaho, in common with the northern half of the continent, had a colder and more humid climate than now. The streams flowing from the mountains were thus enlarged, and more earth and stones were swept into the channels of the main streams than they could transport.

The great climatic change which caused about one-half of the North American Continent to be covered with glacial ice left no records in southeastern Washington except those briefly referred to. Glaciers existed on the mountains of Idaho and Washington, but did not invade that portion of the basaltic plateau now included within the boundaries of Washington except locally at the northwest border of the Big Bend country. This advance of ice from the Okanogan country across the canyon of the Columbia dammed that mighty river and caused it to flow across the great plain of the Columbia, through the remarkable gorge known as the Grand Coulée.

Since the Glacial epoch the streams have shrunk in volume, owing to the combined effects of a decrease in precipitation and an increase in the rate of evaporation, and in their weakened condition they have scarcely done more than recut their channels through the gravel and sand previously deposited in them.

The vast amount of work performed by Snake River previous to the Glacial epoch, the halt in the task due to overloading, and the slow rate at which the weakened stream has been able to renew its task in recent centuries, all indicate that the time required for excavating the canyon has been long. We have no accurate measure of this time, but it is safe to say that it embraced millions of years.

The sheets of Columbia lava were essentially horizontal when they were spread out, and, so far as known, they were not disturbed until after the volcanic eruptions, to which they are due, came to an end. Movements in the earth's crust occurred at a later date, however, and the thick series of basaltic layers were broken into blocks measuring many miles on their sides, and these were variously tilted. This breaking and tilting occurred principally to the westward. Some of the tilted blocks extend far up on the eastern border of the Cascade Mountains, showing that the central and southern portions of that magnificent range have been upraised since the period when the Columbia lava was poured out.

In southeastern Washington the basalt has suffered but little from the forces producing elevations and depressions, and over extensive areas the hardened lava is still horizontal. The portion of the lava forming the Blue Mountains has been elevated into a broad, low, flat-topped dome, on the flanks of which, so far as has been learned, the beds of basalt dip away gently in all directions. The movements that have produced these more general changes in the relief of the basalt-

covered country are probably still in progress, as is indicated by the manner in which Walla Walla River is grading up its valley at the western base of the Blue Mountains.

The surface of the basaltic plateau, which is by far the larger part of southeastern Washington, as already stated, remained nearly horizontal, and during the vast lapse of time that witnessed the excavation of Snake River Canyon slowly yielded to the destructive influences of the air and of percolating waters and crumbled to a porous soil. The depth of the products of disintegration and decay is in many places 30 to 80 feet. In fact, over hundreds of square miles the average depth of the fine, yellowish, dust-like material forming the surface layer of rich agricultural districts is as great as the amount just stated.

The surface of the nearly level plateau has been roughened by stream erosion, but its plateau character not destroyed. Numerous level-floored valleys without stream channels bear evidence that the rainfall was formerly more abundant than now. The stream-cut canyons and valleys have been partially filled with fine soil, washed from the adjacent hills or blown from the uplands by the wind. The minor topographic features of the plateau, although due in the main to stream erosion, have been modified to an appreciable and sometimes to a marked extent by the action of the wind.

It is from the soil formed by the slow disintegration and decay of basaltic rocks that the millions of bushels of wheat raised each year in eastern Washington are obtained. The sending of wheat from the State of Washington to the famishing people of India, which has recently been done, is rendered possible because ages ago volcanic rocks capable of furnishing a wonderfully rich soil inundated the Tertiary lowlands where now "rolls the Oregon." The splendid water power at Spokane and the marvelous growth of that charming city can be traced to a climatic change which caused the valley in which it is situated to become deeply filled with stream deposited gravel. When the bright, swift-flowing waters were enabled to clear out their channel, they did not rediscover their former course at all points, but cut across rocky spurs projecting from the sides of the old valley. One such occurrence gave Spokane its beautiful cascade. Many other illustrations of the influence of events in the geological and geographical history of Washington which bear directly on the industrial and intellectual development of the present generation might be cited.

In closing this report of a hasty reconnoissance, I wish to state that the studies thus far made of the geology of Washington show that it is not only one of the most interesting States in the Union to the geologist and geographer, but that it is also rich in mineral and other resources.

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